POLLUTION PREVENTION
IN THE
ELECTRONICS INDUSTRY

DEVELOPED BY:

U.S. EPA/SEMARNAP
POLLUTION PREVENTION
WORK GROUP

MAY 1996

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LIMITATIONS OF THIS MANUAL

This manual provides an overview of the pollution prevention and recycling alternatives that are available in the electronics industry. This report is intended only to assist the user in his or her preliminary research and development of pollution prevention options. Each company is responsible for identifying, evaluating, and implementing pollution prevention practices that are appropriate to its specific situation. By compiling and distributing this manual, EPA and SEMARNAP are not recommending the use of any particular processes, raw materials, products, or techniques in any particular industrial setting. Compliance with U.S. and Mexican environmental laws, occupational health and safety laws, and all applicable federal, state, and local laws and regulations is the responsibility of each individual business. It is not the focus of this document.

The information in this manual is intended to be a relatively comprehensive overview of the documented information on pollution prevention and recycling practices for the electronics industry. However, the collection, organization, and dissemination of pollution prevention information is a relatively new initiative, and an ongoing and evolutionary process. In addition, there are limits to any manual, including this one. Therefore, this summary may not contain every relevant piece of information on pollution prevention and recycling for electronics companies. EPA encourages all users—who discover, in the literature or in the field, pollution prevention options that are not cited in this report—to share this information with EPA. Please submit any corrections, updates, or comments on this report to the following:

Robert D. Lawrence (6EN-XP)
Pollution Prevention Coordinator
U.S. EPA Region 6
1445 Ross Avenue
Dallas, TX 75202
(214) 665-2258

This manual is an assimilation of existing research and case studies of waste minimization and pollution prevention principles. Because of the voluminous amount of such information, referencing sources in the text as and when they are used would make the manual cumbersome for the reader. Therefore, the authors of this manual wish to acknowledge the authors of all of the documents referenced throughout the text and listed in the bibliography section.

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INTRODUCTION

The production of economically competitive products is the driving force behind any successful business. Production frequently requires the use of various chemicals throughout the manufacturing process. The purchase and storage of these chemicals, their use in the process, and the ultimate disposal of the waste generated by the manufacturing process can present many problems. These problems include financial concerns, environmental management, and worker health and safety. Pollution prevention provides an effective means to minimize, and even eliminate, such problems.

The U.S. Environmental Protection Agency (EPA) defines pollution prevention (also referred to as source reduction) as the use of materials, processes, or practices that reduce or eliminate the generation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, and other resources, in addition to practices that protect natural resources through conservation or more efficient use.

Because of the enormous potential for pollution prevention along the U.S.-Mexico border, the Pollution Prevention Work Group was established in February 1992. The lead federal agencies of the Work Group are EPA and Secretaria Del Medio Ambiente Recursos Naturales y Pesca (SEMARNAP). EPA and SEMARNAP also began promoting and coordinating the reduction of pollution through a broad range of approaches: technical assistance, training, public and private sector programs in pollution prevention awareness, assessment of pollution prevention opportunities, policy development and institutional support, and technology development and investment activities.

The purpose of this manual is to provide pollution prevention information for the electronics industry. This manual builds on the efforts of the first two manuals —"Waste Minimization for the Metal Finishing Industry" and "Pollution Prevention for the Wood Finishing Industry." These manuals were the first and second in this series of bilingual pollution prevention manuals prepared jointly by EPA and SEMARNAP. Future manuals will include other industries that are typical in the border area. This manual contains the following sections:

Section I Goals and Benefits of Pollution Prevention

This introduction defines the term "pollution prevention," and provides an overview of the goals and benefits of, as well as methods for developing, a successful pollution prevention program.

Section II Pollution Prevention in the Electronics Industry

This technical section describes various processes and waste streams associated with the electronics industry and pollution prevention options for that industry.

Section III Case Studies

This section includes specific examples of companies that have used pollution prevention techniques. These case studies describe the benefits, particularly cost savings, that these companies have derived.

Appendix Additional Information

This section lists additional technical documents pertaining to pollution prevention opportunities for the electronics industry, and other pertinent information. These documents are currently available only in English.

Attachment A Information on Accessing Pollution Prevention Information Clearinghouses

Attachment B Survey

PLEASE COMPLETE THE SURVEY INCLUDED IN THIS SECTION. Your response provides valuable information for evaluating the usefulness of this manual. Additionally, when your survey is returned, your name will be placed on a mailing list for updates to the manual and other documents as they become available.

Section I

Goals and Benefits of Pollution Prevention

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GOALS AND BENEFITS OF POLLUTION PREVENTION

WHAT IS POLLUTION PREVENTION?

As defined by EPA, pollution prevention (also known as source reduction) is the act of eliminating the pollutant before it is generated. The idea is to prevent the generation of pollution rather than determine what to do (pollution control or waste management) once it is generated. Technically, pollution prevention is a management tool that prevents or reduces pollution at the source through cost-effective changes in production, design, and operation. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, and other resources, in addition to practices that protect natural resources through conservation or more efficient use. Such changes offer industry substantial savings in reduced raw materials, pollution control, and liability costs, as well as, help protect the environment and reduce risks to worker health and safety.

Moreover, pollution prevention is more than just another way to reduce pollution. Pollution prevention is a mind-set. This mind-set continually searches for innovative ways to do things better and to overcome the inherent human resistance to change. Such a mind-set does not accept "that is how we have always done it" as a reason for maintaining a policy or practice.

Source reduction eliminates the pollutant before it is generated. Source reduction opportunities include the following:

! Material changes that substitute less hazardous input materials for process chemicals that generate hazardous waste.

! Change the process design and incorporate current technologies that increase efficiency and reduce or eliminate the amount of pollutants being generated.

! Improve operating practices that promote reuse and recycling over disposal, good inventory control to eliminate the accumulation of unused or expired chemicals, and proper maintenance to prevent leaks and spills.

Table I-1 summarizes specific examples of source reduction opportunities.

Other Environmental Management Strategies

There are numerous pollution control or waste management strategies that are applied only after wastes have been generated, instead of preventing the generation of a pollutant. Therefore, they are not correctly categorized as pollution prevention. Table I-2 provides examples of waste management strategies that are not categorized as pollution prevention.

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TABLE I-1

EXAMPLES OF SOURCE REDUCTION OPPORTUNITIES

Examples of material changes

- ! Purchase raw materials that are free of trace quantities of hazardous or toxic impurities.
- ! Switch to nonlead-based solders.
- ! Use a less hazardous or toxic solvent for cleaning, coating, or finishing.

Examples of more efficient process design changes and current technologies

- ! Redesign equipment and piping to reduce the volume of material contained, thereby reducing losses during batch or color changes, or when equipment is drained for maintenance or cleaning.
- ! Change to mechanical stripping and cleaning devices to avoid using solvents.
- ! Use an alternative cleaning technology, such as supercritical carbon dioxide.
- ! Install a hard-piped vapor recovery system to capture and return emissions.
- ! Use equipment that is more efficient.
- ! Use no-clean and inert gas soldering processes.
- ! Use powder coatings and high-volume, low-pressure (HVLP) spray guns to reduce emissions from painting.

Examples of improving operating practices

- ! Train equipment operators.
- ! Keep solvent tanks covered.
- ! Segregate waste streams to avoid cross contaminating hazardous and nonhazardous materials.
- ! Increase control of operating conditions (including flow rate, temperature, pressure, residence time, and stoichiometry), and change maintenance scheduling, recordkeeping, or procedures to increase efficiency.
- ! Optimize purchasing and inventory maintenance methods for input materials. Purchasing in quantity can reduce costs and packaging material if care is taken to ensure that materials do not exceed their shelf life. Reevaluate shelf life characteristics to avoid unnecessary disposal of stable items.
- ! Prevent leaks, drips, and spills, and use drip pans and splash guards.
- ! Turn off electrical equipment, such as lights and copiers, when not in use.
- ! Place equipment in a manner that will minimize spills and losses during transport of parts or materials.
- ! Recycle rinse water and reuse facility chill water.

The opportunities presented here are pollution prevention options, because they prevent or reduce the generation of pollution.

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TABLE I-2

WASTE MANAGEMENT STRATEGIES THAT ARE NOT POLLUTION PREVENTION

Off-site recycling

! Off-site recycling (for example, solvent recovery at a central distillation facility) can be an excellent waste management option. However, because it does not reduce the actual amount of pollution generated, it is not a pollution prevention measure.

Waste treatment

! Waste treatment involves changing the form or composition of a waste stream, through controlled reactions, to reduce the amount of, or eliminate, the pollutants. Examples include pretreatment, detoxification, incineration, decomposition, stabilization, and solidification or encapsulation.

Concentration of hazardous or toxic constituents to reduce volume

! Volume reduction operations, such as dewatering, are useful treatment approaches, but they do not eliminate or reduce the amount of pollutants being generated. For example, pressure filtration and drying of a heavy metal waste sludge before disposal decreases the sludge water content and waste volume, but it does not decrease the number of heavy metal molecules in the sludge.

Dilution of constituents to reduce hazard or toxicity

! Dilution is applied to a waste stream after it has been generated. Dilution does not reduce the absolute amount of hazardous constituents entering the environment.

Other control technologies

! Control technologies are generally "end-of-pipe" approaches to pollution. Many control technologies that have been used have only collected pollutants and moved them from one environmental medium (air, water, or land) to another. For example, activated carbon filters may prevent air pollution, but they can a create a solid waste problem.

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Many waste management practices used to date have merely collected pollutants and moved them from one environmental medium to another. Companies should recognize that transferring hazardous wastes to another environmental medium is not pollution prevention. For example, solvents can be removed from wastewater by using activated carbon. However, regenerating the activated carbon requires using another solvent or heating, which transfers the contaminants to the air. In some cases, this type of waste management strategy is a valid treatment option. However, too often the result has been to shift a pollutant to a medium that is regulated less stringently.

For example, waste treatment prior to disposal reduces the toxicity and/or disposal-site space requirements but does not eliminate all pollutant materials. Frequently, the effect is to transfer pollution from air or water to land. Conventional waste treatments include processes such as volume reduction, dilution, detoxification, incineration, and stabilization.

Off-site recycling, which is another waste management strategy, is vastly preferable to other forms of off-site waste handling, because it helps to preserve raw materials and reduce the amount of material that will require disposal. However, off-site recycling is likely to have more residual waste that requires disposal than closed-loop recycling (reuse) performed at the production site. Furthermore, waste transportation and the off-site recycling process increase the risk of worker exposure and release to the environment.

The waste management hierarchy, represented on Figure I-1, prioritizes true pollution prevention options (source reduction and recycling reuse) over pollution control measures (treatment and disposal), in order, from the most environmentally beneficial to the least environmentally beneficial. Specific technical information on pollution prevention options for the electronics industry is contained in Section II of this manual.

POLLUTION PREVENTION GOALS

The goal of a pollution prevention program is to improve the quality of the environment by eliminating or reducing the generation of waste at the source. Pollution prevention includes any action by a company to reduce the amount of waste generated by a manufacturing process prior to off-site recycling, treatment, or disposal of the waste. To effectively accomplish this, the program must include an ongoing, comprehensive assessment of the operations at a facility.

BENEFITS OF A POLLUTION PREVENTION PROGRAM

Businesses and governments have strong incentives to reduce the toxicity and volume of the waste that they generate. ***As pollution prevention activities lower operating costs, production costs will decrease. Therefore, companies with an effective, ongoing pollution prevention program will have a significant competitive advantage.***

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The following subsections discuss the benefits that can be gained from a pollution prevention program, as follows:

- ! Protect human health and environmental quality.
- ! Reduce operating costs.
- ! Improve employee morale and participation.
- ! Enhance the company’s image in the community.
- ! Assist in compliance with environmental laws.

Protect Human Health and Environmental Quality

Reducing the release of pollutants to air, land, and water will enhance the environment and protect human health. Releases typically containing harmful pollutants that can be reduced significantly by pollution prevention techniques include the following:

- ! Air emissions, including solvent fumes, fine particulates, and carbon monoxide
- ! Land disposal, including ash from incineration, waste solvents, and debris
- ! Water disposal, including wastewater contaminated with solvents and other toxic materials

Volatile organic compounds (VOC) typically comprise a significant amount of the solvents used in the electronics industry. VOCs are central nervous system depressants. High exposures (hundreds to thousands parts per million in the air) may result in giddiness, confusion, unconsciousness, paralysis, and death from respiratory or cardiovascular arrest. Long-term exposure may affect behavior. Some VOCs are suspected carcinogens, too.

Poor ventilation, mishandling of chemicals, and a lack of proper safety equipment can affect the health and safety of employees. An informative employee training program is an important way to reduce accidents. Reducing the amount of chemical materials and wastes at a facility is also beneficial, because it reduces the amount of space required for storage and the potential for accidental spills. Furthermore, reducing the volume of pollution generated minimizes the amount of hazardous waste requiring transport and disposal.

Reduce Operating Costs

An effective pollution prevention program can yield cost savings that will more than offset program development, implementation, and operational costs. Cost reductions may be immediate savings that appear directly on the balance sheet or anticipated savings that are based on avoiding potential future costs. Cost savings are particularly noticeable when the costs resulting from the treatment, storage, or disposal of wastes are allocated to the production unit, product, or service that produces the waste.

Materials costs, or the costs of purchasing materials, can be reduced by adopting production and packaging procedures that consume fewer resources. This approach uses resources more efficiently, and reduces the quantity and toxicity of waste generated. As wastes are reduced, the percentage of raw materials converted to finished products increases. This results in a proportional decrease in materials costs.

Waste management and disposal costs may be reduced when less waste is produced. Required procedures for proper handling of the waste at the facility —in addition to specific treatment, disposal, and transportation methods—are typically labor-intensive and very costly. These requirements and their associated costs are expected to increase.

Production costs can be reduced through a pollution prevention assessment. When people examine production processes from a pollution prevention perspective, they find opportunities for increasing efficiency that might not, otherwise, have been noticed. Production scheduling, material handling, inventory control, and equipment maintenance are areas in which facilities can work to reduce the production of waste of all types, thereby controlling the costs of production.

Energy and water usage costs and will decrease as the facility implements pollution prevention measures in various production lines. In addition, by thoroughly assessing how operations interact, companies can reduce the energy and process water used to operate the entire facility.

Improve Employee Morale and Participation

Employees are likely to feel better about their company when they believe that management is committed to providing a safe work environment and is acting as a responsible member of the community. By participating in pollution prevention activities, employees have an opportunity to be part of a "team," and interact positively with coworkers and management. Helping to implement and maintain a pollution prevention program will typically increase each employee's sense of commitment to company goals. This positive atmosphere helps to retain a competitive work force and to attract high-quality new employees.

Enhance the Company's Image in the Community

The quality of the environment has become an issue of critical importance to society. Your company's policy and practices for controlling waste increasingly influence the attitudes of the local community at large.

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Community attitudes are more positive toward companies that operate and publicize their pollution prevention programs. If a company creates environmentally compatible products, and avoids excessive use of material and energy resources, the company's image will be enhanced both in the community and with potential customers and consumers.

Assist In Compliance With Environmental Laws

Mexico's environmental laws include administrative penalties that entitle government inspectors to require temporary or permanent closure of businesses that are not in environmental compliance. A pollution prevention program that includes standard operating procedures that comply with environmental laws and regulations is helpful. By following the program, a company increases its chances of avoiding violations and associated penalties.

DEVELOPING A POLLUTION PREVENTION PROGRAM

Keys to a Successful Program

The following characteristics are crucial to the success of a pollution prevention program:

- Support from top management
- Champions—personnel who actively promote the program
- Written mission statement backed by company policy
- Defined and measurable goals
- Solicitation of, and follow-up on, employees' suggestions
- Continuous reevaluation as economic conditions and/or the manufacturing processes change

Any effective and enduring program—including pollution prevention—must have the ***support of top management.*** Executives and managers set the tone for the pollution prevention program. Companies need to integrate pollution prevention into their business practices to build and sustain a successful program. As production-level employees see a company-wide commitment, they will be more likely to support the program. This is crucial, because they will be the most active personnel in both identifying pollution prevention opportunities and in implementing solutions. The company should write a pollution prevention mission statement to emphasize its commitment to the program.

Next, a pollution prevention team should be organized that includes ***managers, supervisors, and line workers.*** Those who are knowledgeable about the processes that generate wastes should be involved from the beginning. Recognize those who contribute, and continually encourage suggestions from all employees. Designate one or more pollution prevention champions from the team. Champions are assigned to overcome resistance to the program and obstacles to change. The champions should be high-profile employees that are respected and trusted by their coworkers. The pollution prevention team should write a plan that details (1) methods for encouraging participation, (2) stipulations for employee training, (3) procedures for conducting process assessments, and (4) criteria for implementing pollution prevention projects. If top management is not on the pollution prevention team, the plan should be presented to, and agreed to by, management. This plan will be a starting blueprint for the program, but it should be updated whenever necessary, because a company should continually strive to improve the program.

After the general organization of the program has been established, the team must ***establish goals for the program.*** The team may want to establish both an ultimate goal to pursue—zero discharge, for example—and one or more short-term achievable goals—reducing waste by 10 percent annually, for example. Goals do not need to remain unchanged. Build on the successes achieved, and update your company's goals. Pollution prevention is a continuous process.

Throughout the process ***employee suggestions must be actively encouraged and seriously considered.*** Suggestions should be evaluated quickly and put into practice if they meet the designated criteria. If you choose not to implement a particular suggestion, explain your reasons to the employee who suggested it. Reinforce the importance of each individual's contributions and their value to the overall company objectives.

The Pollution Prevention Process

The process, graphically represented in Figure I-2, can be divided into the following basic steps:

1. Characterize the production process.
2. Assess waste streams.
3. Identify pollution prevention options.
4. Evaluate the economic and product quality implications of each option.
5. Choose and implement the best options.
6. Measure results.
7. Reevaluate the program.

To complete steps 1 and 2, you must collect information about your facility. Collect as much information as you need, but remember to keep your data collection system as simple as possible. The information gathered will help to focus the efforts during the ensuing phases of the program.

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Possible sources of useful information include the following:

- Regulatory information (such as permits, waste shipment manifests, and emission inventories)

- Engineering information (such as process flow diagrams, operating manuals, equipment lists, and material balances)

- Production data (such as production schedules, product and raw material inventories, and material safety data sheets)

- Accounting data (such as hazardous and nonhazardous waste handling and disposal costs; product, energy, and raw material costs; and operating and maintenance costs)

Under step 3, members of the pollution prevention team and other employees will identify many options. Encourage creative and independent thinking, and use brainstorming sessions. Many other options—and information useful in evaluating options—can be obtained through (1) trade associations, (2) published literature, (3) other companies, (4) government agencies, (5) equipment suppliers, and (6) technical consultants. Some sources of information are presented in an appendix to this manual.

Under step 4, identify and document the benefits and costs associated with each project. Benefits and costs may be economic, technical, or environmental.

After the options have been evaluated, the pollution prevention team can choose the options that meet the company's criteria for technical and economic feasibility (step 5). Some projects may be worth doing for reasons other than pollution prevention. For example, some options may improve economic competitiveness or increase employee safety. Options that do not involve a large capital expenditure—such as procedural or housekeeping changes—can be implemented quickly after the appropriate reviews and approvals have been obtained. The other approved projects may be implemented as soon as it is technically and economically possible.

Under step 6, compare your achievements to the goals that were established for the program. How much has waste been reduced? What costs or savings have resulted? How has the product quality been affected?

Under step 7, the pollution prevention program is periodically reevaluated to identify ways to improve and adapt it to changes in the industry and in the regulatory environment.

Sustaining the Program

Maintaining a successful pollution prevention program cycle after cycle is challenging but can provide large dividends for a company. For example, such a program can achieve the following:

- Incrementally lower material and disposal costs.

- Focus employees on continuous improvement.

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! Reinforce a positive view of the company with its employees and within the community.

Following are suggestions for maintaining the momentum of a pollution prevention program:

! Reemphasize the economic benefits to employees and management.

! Publicize success stories, and reward innovation.

! Hold operating units accountable for the full costs of controlling and disposing of any waste that they generate.

! Rotate the members of the pollution prevention team to sustain an inflow of fresh ideas.

! Provide updated training.

Section II

Pollution Prevention in the Electronics Industry

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SECTION II

POLLUTION PREVENTION IN THE ELECTRONICS INDUSTRY

The main purpose of this section is to present practical pollution prevention options for the electronics industry. Many of the options presented in this section can save a company money as well as decrease waste. Section III, *Case Studies*, provides examples of companies that have developed a pollution prevention program and implemented pollution prevention techniques.

In order to make the information in this manual more presentable—and to minimize duplication—the electronics industry has been divided into two segments: (1) microelectronics, and (2) macroelectronics. With this in mind, Section II has been divided into three chapters. The first chapter presents general pollution prevention options applicable to both segments of the industry, the second chapter discusses pollution prevention options for the microelectronics industry, and the third chapter discusses pollution prevention options for the macroelectronics industry.

The manufacturers within the electronics industry vary widely in size and products; consequently, not every option presented will be appropriate for every company. Each company should implement the portions that reduce pollution the most, while maintaining or improving product quality and the company's bottom line. The list of options presented in this section is not comprehensive, nor is the information an attempt to render engineering services. Rather this section is intended to introduce the reader to a list of potential solutions to environmental problems, and, perhaps, a new way of thinking. The reader is encouraged to do further research on any promising options. The Appendix to this manual provides additional sources of information, which may be used as a starting point.

As mentioned in Section I, there is a hierarchy of options that deal with waste. The most preferable is source reduction—decreasing the amount of hazardous material used, then recycling or reusing the material, followed by treating the waste and finally disposing of it. Although recycling is not necessarily a method of pollution prevention, some aspects of recycling are covered in this section.

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Chapter 1

GENERAL POLLUTION PREVENTION METHODS AND COMMON PRACTICES

This chapter presents various pollution prevention options that can be applied industry-wide.

The electronics and computer industry, which is the largest manufacturing employer in the United States, accounts for about 11 percent of the U.S. gross domestic product. The electronics industry is also very important in Mexico, especially along the U.S.-Mexico border, where about one-half of the respondents to a recent Texas Natural Resource Conservation Commission survey of maquiladoras indicated that they were in the electronics industry.

Perhaps no other industry is changing as rapidly as the electronics industry. As the pace of technological change accelerates, product life cycles are reduced, and customer expectations are raised. This might be the reason so many electronics companies have embraced the movement toward quality and continuous improvement. The familiarity of electronics companies with rapid change and continuous improvement has made pollution prevention a natural extension of many existing corporate cultures.

Pollution prevention can improve worker health and safety, and increase the profitability of the business. In the simplest form, a company's finances may be calculated as follows:

Profits = Income - Expenses

Pollution prevention can decrease two major expenses: raw material costs and the cost of waste disposal. Reducing the amount of waste generated decreases the waste requiring disposal. Wastes often consist of potential product that has been squandered. For example, a finishing material, such as paint, that ends up on the floor instead of on the product is a purchased raw material that could have been sold as part of a finished product. On the floor, it is merely a waste. Not only is that wasted finishing material never sold as part of a product, but it will cost money to clean up and dispose of; also, regardless of whether your company is in the U.S. or Mexico, the cost of disposal is expected to continue to increase. On the other hand, if your company had equipment that applied paint with less overspray, less paint would be wasted, and the company would need to purchase less paint, thereby decreasing raw material and disposal costs.

DESIGN FOR ENVIRONMENT

Design for Environment (DfE) aims to minimize environmental impacts and use resources efficiently. The aim of DfE is to promote sustainable development. Simply stated, sustainable development consists of meeting the needs of the current population without compromising the ability of future generations to meet their needs. DfE considers the environmental impact of a product throughout its entire life cycle, including raw material acquisition; processing; manufacturing and assembly; product use, service, and repair; retirement; and treatment and disposal. A life-cycle assessment is conducted to gain an understanding of these impacts.

A life-cycle assessment includes three phases of analysis: (1) inventory analysis, (2) impact analysis, and (3) improvement analysis. During the inventory analysis, all energy and raw material requirements, emissions to air and water, solid wastes, and other releases are quantified for the product throughout its entire life cycle. During the impact analysis, the effects of the resource requirements and wastes generated are qualitatively and/or quantitatively assessed. The improvement analysis evaluates the opportunities to reduce the environmental impact on the production, use, and retirement of the product. This assessment naturally leads into product design and DfE. Therefore, environmental considerations should be included as a design criteria, as are legal, cultural, performance, and cost criteria.

Design objectives that minimize environmental impact include the following:

! Use recycled or renewable sources of raw material.

! Design a product to be more energy efficient.

! Make a product with a longer useful life.

  - Increase reliability.
  - Simplify maintenance.
  - Increase durability.
  - Design for adaptability.
  - Plan for product remanufacture or reuse.

! Make a product that is easier to recycle or that, when disposed of, has a lesser environmental impact.

These types of objectives take different forms for different products. For example, making tennis shoes with a longer useful life means making them more durable. However, for the electronics industry—where technology changes rapidly—a better example of extending the useful life of a product would be to make a computer more easily upgradeable or adaptable.

HOUSEKEEPING

Housekeeping efforts are often the first made by a facility attempting to minimize waste. This is to be expected, because such efforts often require relatively low capital commitment and are often perceived as simple common sense solutions. But these types of changes are often people-based, rather than technology-based, and can be more difficult to maintain over the long term. The best manner in which to implement effective housekeeping changes is to make it easy for employees to do the right thing.

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Facilitating waste stream segregation is a common housekeeping measure that can make the difference between reclamation and incineration. Separation of halogenated and nonhalogenated solvents, acid/solvent mixtures, and chelated and nonchelated chemicals is especially important in managing waste streams in the electronic industry. However, many of these chemicals may be resistant to recovery options that use standard equipment.

Controlling the frequency with which inventory is purchased can reduce generation of waste. In the fabrication of products such as capacitors, tight restrictions on the shelf life of resins and polymers can force disposal of otherwise usable products. Purchasing smaller amounts more frequently may increase purchase costs, but it decreases costs associated with disposal.

Other housekeeping changes may include spill and leak prevention, contamination control, and equipment maintenance.

INVENTORY CONTROL

Properly controlling raw materials, intermediate products, final products, and wastes is a significant way to minimize pollution. Wastes often consist of either raw materials that are out of date, no longer used, or unnecessary; or final products that are off-specification or damaged. Including wastes in an inventory program can make them more recoverable. Improving inventory control ranges from simple modifications in the procedure of ordering materials to innovative just-in-time (JIT) manufacturing techniques. ***Improved inventory control can reduce material costs and reduce waste generation and its associated costs.***

The following changes can improve your inventory management:

- Purchase only the amount of material needed.
- Review materials for hazardous content, and examine alternatives that are less hazardous.
- Track and control the use of materials to reduce excess use.
- Make specific employees or departments responsible for the purchase and disposition of supplies and materials.

REDUCE PACKAGING WASTE

Packaging can (1) protect a product during transportation, (2) make handling easier, and (3) provide information about a product. However, packaging is often a significant component of a company's solid waste stream.

Where practical, the easiest way to reduce packaging waste is to ship a product without packaging.

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However, some packaging is often required. In this case, the following options can minimize its environmental impact:

- Reduce the amount of packaging used.
- Reconfigure the packaging so products can be transported more efficiently.
- Use reusable packaging.
- Use packaging composed of more biodegradable materials.
- Use recycled materials in packaging.

The amount of packaging required for each unit of product can be reduced by shipping in bulk and changing the amount of protection that the packaging provides. The packaging may be determined to be excessive and provide more protection than the product needs. Perhaps the product can be modified to require less packaging. A more sturdy product may require less packaging and may better serve the customer.

Wholesale and intermediate products can often be shipped in reusable containers. Tanks, wire baskets, wooden shooks, and plastic boxes are often used as reusable containers. Procedures for collecting and returning, as well as for storing and handling, reusable containers may prevent them from being discarded.

Finally, the impact of packaging on the environment may be reduced by using materials that are more biodegradable or using packaging that has a high content of recycled material. Inks and pigments used in package labeling are now available that are less harmful than those traditionally used, but just as effective for most applications.

ESTABLISH A RECYCLING PROGRAM

Recycling options will be identified in each of the three chapters in this section. Although most recycling is not source reduction, it can be a relatively easy way to reduce waste and costs simultaneously. Recycling reduces a company's overall waste stream. A smaller waste stream can (1) require fewer garbage collections, (2) enable the company to rent a smaller dumpster, and (3) reduce the costs of the ultimate destruction or disposal of the waste. Recycled materials may be (1) purchased by a recycler, (2) collected without charge, or (3) collected for a charge. This depends on the materials being recycled and the local market. Even if a recycler charges to collect the materials, the charge is usually less than the cost of disposing of the material as waste.

Implementing a recycling program involves four basic steps: (1) analyze your company's waste stream, (2) identify recycling opportunities in your area, (3) negotiate a contract with a recycler, and (4) design a recyclables collection program.

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First, analyze your company's waste stream. Identify the materials that you may want to separate for recycling, such as solvents, scrap metal, paper, or cardboard.

Second, identify recycling opportunities in your area. To be a candidate for recycling, a material must have a market. That is, someone must be able to use the old materials in new products. Use the telephone to ask the following questions:

- What materials are recycled locally?
- How are materials collected and processed?
- How much is paid or charged for picking up different recyclables?

Third, negotiate a contract with a recycler. Traditionally, recycling markets have had frequent changes in the amount paid per pound of material. It is important to find a reliable company that will weather the market fluctuations. Ideally, a company will accept a wide range of materials so that you will have the option to expand the recycling program.

Fourth, design a recyclables collection program. To obtain maximum value, a recycled material must be separated from the waste stream and, usually, from other recycled materials. For a collection program to be successful, employees must be able to easily participate in it.

- Place recycling containers in convenient locations (for copy paper—next to the copier; for aluminum cans—in the lunch room; and for used solvents—near cleaning operations).
- Clearly label containers.
- Place waste baskets near the recycling containers so that recyclables are not contaminated.

If your company's area does not have a recycler that will accept a specific waste, there are still a few options. One alternative is to talk with other companies in your area. Perhaps a nearby company could use your company's waste. If a nearby company has the same waste, you may be able to combine you wastes with theirs for a sufficient quantity to make it attractive to a recycling company. Another option is to contact a waste exchange. Over 50 waste exchanges are operating in North America. Waste exchanges help companies generating waste to find possible markets for the waste. ***The Resource Exchange Network for Eliminating Waste—located in Austin, Texas—helps companies throughout the southwest United States and Mexico ([512] 239-3171).***

POLLUTION PREVENTION IN THE OFFICE

Striving to reduce waste should not end with industrial operations. Many valuable opportunities to reduce or reuse wastes are overlooked in office settings. Pollution prevention techniques are applicable for offices of any size. What kind of wastes are generated by offices? Paper, cardboard, toner cartridges, packing waste, newspapers, food, cans, glass and plastic containers, correction fluid, pens, pencils, cleaning products, rags, and light bulbs are among the typical office wastes. Fortunately, office wastes can be reduced by adopting some simple prevention and recycling methods. The following benefits can be achieved by implementing a pollution prevention program for the office:

- Savings from lower procurement and disposal costs
- Reduced waste
- Reinforcement of pollution prevention as a company-wide effort by making office workers active participants

By targeting procurement, waste can be reduced from the start. Make preventing waste generation one of your company's procurement priorities. For example, work with your suppliers to purchase (1) material with less packaging, (2) reusable, recyclable, or refillable, instead of disposable, items, (3) materials that are less toxic, and (4) items made from recycled materials. Procurement can also be used as an inventory control. Being careful not to buy excessive amounts of any item will reduce the amount of waste generated by disposing of unused, but outdated or expired, items.

The following can reduce office waste:

- Use central files instead of giving a copy of each report or memo to everyone.
- Save documents on disk instead of making hard copies.
- Make double-sided copies whenever possible.
- Donate used magazines and journals to libraries or hospitals.
- Return or reuse wooden pallets and other packaging.
- Proofread and correct documents on the computer screen before printing.
- Maintain equipment regularly for maximum use.

For wastes that are generated, recycling used office materials can help to further decrease a company's waste stream.

Another easy way to save money is to consider energy efficiency when purchasing office equipment, such as computers, copiers, refrigerators, and light bulbs. An energy efficient office helps the environment and your company's electric bill.

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Chapter 2

THE MICROELECTRONICS INDUSTRY

This chapter focuses on an area of rapid growth and constant change—the microelectronics industry. The chapter is divided into three subsections: Microelectronic Products, Processes and Typical Waste Streams, and Pollution Prevention Options for the Microelectronics Industry. Microelectronic Products will introduce the general categories of products that will be covered in this chapter. As the products are introduced, the general processes used to manufacture these products will also be presented. Processes and Typical Waste Streams will present more detail on specific steps of the manufacturing processes and the waste streams that they generate, which can be targeted for pollution prevention. Pollution Prevention Options for the Microelectronics Industry will focus on methods of reducing waste generation within the processes detailed in the prior subsection.

MICROELECTRONIC PRODUCTS

Microelectronics are components of electronic products used in residential, commercial, industrial, and military applications. The microelectronics industry manufactures many devices; however, a few of them dominate the industry, and production of two of these devices—printed circuit boards and semiconductors—is growing rapidly. Manufacturing of printed circuit boards and semiconductors manufacturing also results in large volumes of wastes. Integrated circuits are the major products of the semiconductor industry. Integrated circuits are combinations of discrete semiconductor devices—for example, resistors, capacitors, or transistors.

The printed circuit (PC) board (or wiring board) industry consists of facilities with varying levels of production and varying types of applications, including facilities that are totally dedicated to PC boards, captive facilities, small job shops, and specialty shops that perform high-precision work. The application of a PC board will determine the design, amount, and complexity of the board circuitry. These factors, in turn, affect the amount of wastes produced during manufacturing. Products that use PC boards include business machines, computers, military applications, communications equipment, control equipment, and home entertainment equipment.

Semiconductors perform various functions in electronic circuits, including information processing and display, power handling, data storage, signal conditioning, and the interconversion between light energy and electrical energy. Semiconductors are widely used in products such as computers, consumer appliances, communication equipment, electrical control devices, robots, and scientific and test equipment.

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PROCESSES AND TYPICAL WASTE STREAMS

This section provides an overview of the typical processes and waste streams in the PC board and semiconductor industries. These industries were selected because the production of PC boards and semiconductor devices dominates the microelectronic components industry. Other microelectronic devices, which are not addressed here, share similar manufacturing processes and produce similar waste streams. The processes used to manufacture PC boards and semiconductors typically result in large volumes of wastewater, solid hazardous waste, liquid hazardous waste, and air emissions. Some of these waste streams may be particularly toxic to human health and the environment. Several PC board and semiconductor manufacturing processes—and the waste streams from these processes—can be targeted for pollution prevention efforts.

The following subsections summarize the main processes used to manufacture PC boards and semiconductors.

Printed Circuit Boards

PC boards (also called printed wiring boards) are metal clad dielectrics with conductors etched onto one or both sides of the board. Figure II-1 shows the major steps for manufacturing and assembling PC boards.

Three methods for fabricating PC boards are the (1) additive method, which involves electroless plating on bare boards to build up circuit layers; (2) subtractive method, which involves etching the board, or removing metal from a metal-clad board in the desired circuit pattern; and (3) semiadditive method, which is a combination of the additive and subtractive methods.

In the assembly process, electrical components are placed on the boards, the boards are fluxed, and the components are affixed and soldered to the boards. In wave, dip, and drag soldering, a molten solder is deposited on the board. Flux is applied to reduce the surface tension and oxides on metal surfaces so that the solder will flow evenly. The three most common types of flux are rosin, organic acid, and synthetically activated fluxes. Flux residue and other contaminants need to be removed from the board after soldering. In general, contaminants include (1) water-insoluble or oily materials, such as oils, greases, rosin, and waxes; (2) water-soluble materials, such as rosin flux activators, sodium chloride, and plating and etching salts; and (3) particulates, such as dust, and machining, drilling, and punching fragments.

If no-clean soldering processes are not utilized, cleaning processes are required to remove residues from the board. These include chlorinated solvents—including chlorofluorocarbons (CFC)—and aqueous and semiaqueous systems. Various solvents—such as 1,1,1-trichloroethane (TCA), acetone, alcohol, and 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113)—are used in various steps of the PC board assembly process for mechanical and manual cleaning applications.

On a traditional PC board, electronic components are affixed to the board by drilling holes in the board, inserting and crimping the leads, and then soldering the components to the board. There is currently a

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trend toward surface mount technology (SMT). Surface-mounted devices are small

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and have no connector leads. Because no holes are needed, the components are more densely packed on the board. SMT requires cleaners that can penetrate the smaller crevices and spacing between the components and the board. The recent phase-out of ozone-depleting substances such as TCA and CFCs, has led to a higher use of aqueous and semiaqueous cleaning systems.

Semiconductors

A semiconductor is a tiny complex of electronic components and their connections that is produced in or on a small slice of material, which may be composed of silicon, germanium, gallium arsenide, gallium phosphate, gallium arsenic phosphide, and semiconducting crystals. A large percentage of the ingots manufactured are silicon-based. Electrical current flows through a solid medium instead of a gas or vacuum as in other electrical devices.

The semiconductor industry is expanding to meet the demands of a technically oriented society that desires to process information faster and more efficiently. This industry has exploded in the last 20 years, with the production of integrated circuits supplanting the production of electron tubes and discrete semiconductor devices, such as resistors, capacitors, and transistors. The application of a semiconductor will determine the base material and the design, amount, and complexity of the circuitry. The base material and circuitry engineering are factors in the amount of wastes that are produced during manufacturing.

Figure II-2 shows the major steps for manufacturing and assembling semiconductors.

Typical Waste Streams and Waste Management Practices

The PC board and semiconductor industries generate numerous waste streams (Table II-1), including wastewater, spent process solutions, waste solvents, wastewater treatment sludges, solids, and air emissions. The following paragraphs discuss the major waste streams generated by the PC board and semiconductor industries, and the practices typically used to manage these wastes.

Wastes from PC board and semiconductor facilities can be managed onsite or offsite, depending on (1) the characteristics of the waste, (2) the resources of the facility, (3) the availability and cost of off-site treatment and disposal facilities, and (4) regulatory requirements. These industries typically treat rinse waters onsite and then discharge to the sewer, and dispose of concentrated wastes—such as wastewater treatment sludges, process baths, and waste solvents—offsite.

In the electronics industry, components are generally cleaned after soldering to remove contaminants, which originate from the fluxes used to promote the wetting necessary for the formation of good solder joints. The flux residue can interfere with future processes and reduce the aesthetics and reliability of a component. Traditionally, chlorinated, fluorinated, and other halogenated solvents have been used to remove these residues. Halogenated solvents are used because of their stability, ease of drying, and effectiveness in removing oils. These same characteristics, which make these solvents effective in cleaning processes, have detrimental effects on the environment. Solvent evaporation has been investigated for its role in stratospheric ozone

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TABLE II-1

TYPICAL WASTES GENERATED IN THE MICROELECTRONICS INDUSTRY

Waste Stream	Generating Process	Example of Waste Stream
Acid solutions	! Etching	! Hydrofluoric acid etch of silicon wafers ! Sulfuric acid/peroxide removal of copper from PC boards
Solvents—nonhalogenated	! Cleaning ! Photolithography	! Acetone cleaning of silicon wafers ! Xylene as solvent in photoresist
Metal-bearing solutions	! Electroplating ! Stripping ! Rinsing	! Copper and solder plating of PC boards ! Removal of solder and copper from PC boards ! Cleanout of metallization equipment for semiconductors ! Removal of processing solution from plated parts
Solvents—halogenated	! Drying ! Degreasing	! Freon drying of completed components ! 1,1,1-Trichloroethane degreasing of components
Alkaline solutions	! Cleaning ! Stripping	! Alkaline detergents used for pre-plate cleaning of parts ! Ammonium hydroxide cleaning of silicon wafers ! Sodium hydroxide stripping of photoresist
Sludges	! Wastewater treatment	! Calcium fluorides from neutralization of hydrochloric acid ! Metal hydroxides from precipitation treatment of electroplating rinses
Scrap	! Wafer fabrication ! Trimming ! Rejects from testing	! Silicon from slicing of semiconductor crystals ! Fiberglass with solder and copper from PC boards ! Integrated circuits with heavy metals from doping and layering
Photoresists	! Photolithography	! Pattern definition during fabrication of semiconductors and PC boards
Fluxes	! Soldering	! Fluxes with copper and lead from PC board assembly/fabrication

depletion, global warming potential, and formation of smog. Using halogenated solvents not only generates hazardous solvent wastes, but it also creates work conditions that may be detrimental to the health and safety of workers. Because environmental regulations restrict the use of such solvents, many industries are attempting to reduce or eliminate their use of halogenated solvents. Additional restrictions are expected.

Wastewaters are generated from numerous processes—including cleaning, etching, stripping, cooling, finishing, and exhaust scrubbing—and often constitute the largest volume of waste generated by PC board and semiconductor operations. The rinse waters typically have a low pH resulting from acid cleaning operations, and may contain numerous pollutants, including suspended solids, metals, fluoride, phosphorus, and chelating agents. Typical waste management practices include a combination of waste stream segregation, in-line treatment, end-of-pipe treatment, and off-site disposal and treatment. Metals are usually removed from the wastewater with a combination of pH adjustment, coagulation, flocculation, precipitation, and filtration, which produces a sludge that is disposed of offsite. Cyanide-bearing waste streams are segregated for cyanide destruction before treatment, or are transported offsite for treatment and disposal.

Spent hydrofluoric acid is the principal waste acid solution; others include sulfuric, nitric, fluoboric, hydrochloric, and acetic acid solutions. Spent acid solutions may be segregated for off-site disposal or discharged to the facility's wastewater treatment system for neutralization and sewer discharge. The principal components of the facility effluent include fluoride, toxic organics, heavy metals, and, in some instances, suspended solids. Wastewaters may contain several heavy metals resulting from electroplating operations, including chromium, copper, lead, nickel, and zinc. In addition, significant concentrations of arsenic are found in rinse waters of facilities that use gallium arsenide and indium arsenide as raw material for crystals. The waste streams from layering (metallization) include spent solutions of precious metals, heavy metals, and acids, and a large volume of dilute acid/water wastewater.

Spent chlorinated organic solvents may be gravity-separated and recovered in-house, or transported offsite for reclamation, or treatment and disposal. The major wastes in fluxing and soldering are the solder wastes, which contain lead and solvents needed to clean the boards after soldering. Spent plating baths result from the electroless copper deposition process and electroplating with copper, tin/lead solder, and precious metals. These waste streams constitute a significant volume of waste generated by PC board operations. Spent electroless copper is not amenable to treatment by traditional metal flocculation, coagulation, and precipitation methods, because the copper is in a complex chelated form. Therefore, spent electroless copper baths are usually drummed and hauled away for treatment and disposal. Spent resist stripper solution contains dilute caustic soda (sodium hydroxide) and chemical components of the resist, including epoxy polymers, chlorinated aromatic organics, methacrylates, and other organic compounds. The spent resist stripper solution typically is drummed and hauled offsite for treatment and disposal. Fluoride originates from hydrofluoric acid, which is used as an etchant and cleaner. The major source consists of spent hydrofluoric acid solutions; the minor source is waste rinse water.

Airborne particulate matter is generated by cutting, sanding, drilling, and slotting operations during board preparations. The particulates are typically collected by using air pollution control devices, or are manually swept up, and are disposed of, with other solid wastes, at landfills. Wet air scrubbers may be used to remove acid, alkaline, and solvent fumes in exhaust from cleaning, etching, and degreasing operations. The scrubbed air passes to the atmosphere, and the scrubber liquid is neutralized with other acidic waste streams. Organic fumes from degreasing operations may be treated by passing the air stream over a bed of activated carbon, which adsorbs the organic vapors. In many instances, however, airborne emissions are discharged to the atmosphere without treatment.

Suspended solids may arise in waste streams from wafer slicing, grinding, and lapping operations. This waste stream may be hauled off for disposal or discharged to the facility's wastewater treatment system for treatment, if necessary.

Waste from the oxidation step includes silicon dioxide or other raw material, hydrofluoric acid, and wafer rinse water.

The doping process produces solid wastes containing arsenic, antimony, phosphorus, arsine, diborane, and waste pump oils.

The photolithography process (photoimaging) produces a substantial portion of the wastes in the semiconductor industry. The major waste streams are waste developer (xylene and other nonhalogenated solvents or caustic) and waste photoresist (orthodiazo-ketone or isoprene rubber). Spent process solutions from photolithography operations—such as resist, resist stripper, and developer—may contain mixtures of caustics, chlorinated aromatic organics, polymers, and other organic compounds. These wastes are usually containerized and hauled off for treatment and disposal.

POLLUTION PREVENTION OPTIONS FOR THE MICROELECTRONICS INDUSTRY

Source Reduction through Material Changes

DEIONIZED WATER

Because the electronics industry requires high-purity process chemicals, it is likely that purified water would be in widespread use. This is certainly the case in segments of the semiconductor industry. However, large numbers of other electronics facilities still use tap water—which contains high concentrations of dissolved ions—in process solutions and rinsing systems. When treated by conventional precipitation methods, this water can yield sludge that contains as much as 90 percent, by volume, precipitated hard-water ions. ***Using high purity or deionized water (instead of tap water) for cleaning not only reduces the volume of sludge generated, but also enhances the performance of recovery technologies, such as ion exchange and rinse water reuse.***

FLUXING AND SOLDERING

Traditionally, environmentally harmful CFC compounds were used in the electronics industry to clean the residue left behind by conventional fluxes. Excess flux must be removed from each board. Therefore, if excess flux can be minimized or eliminated, the chemicals used to remove the excess flux can also be minimized or eliminated. Several alternative fluxes (often referred to as "no-clean fluxes") are designed to leave a minimal residue that does not require an additional process step for cleaning.

Alternative Fluxes

Two types of alternative fluxes are water-soluble and low-solids fluxes. These fluxes require cleaning after soldering; however, they can be cleaned with alcohol or aqueous-based cleaners that are more environmentally benign than traditional solvents. One example of this type of flux is a nontoxic, nonflammable, citric acid-based flux developed by Sandia National Laboratory.

Using low-solids fluxes (LSF) before soldering results in little or no visible residue on PC boards. Therefore, ***cleaning with solvents is not needed.*** LSFs contain only 1 to 10 percent nonvolatile materials by weight, compared to 15 to 35 percent found in conventional fluxes. LSFs are noncorrosive and have high insulation resistance, thereby preventing the need for removal of trace residues in most cases. However, even trace residues may affect reliability of certain products. Other processes that improve the reliability of the component include the LSF applicator and inert atmosphere ovens. AT&T developed the LSF applicator to apply less flux via a spray fixture that can be adjusted very precisely to achieve controlled uniform flux coverage. Because the small quantity of organic solids in LSFs is volatile, reoxidation of exposed surfaces during reflow is a major cause of poor soldering. Eliminating oxygen by creating an inert atmosphere (nitrogen) improves solder reliability with LSFs. Alteration of equipment may be necessary to use LSFs, especially if an inert atmosphere is needed for best results. The purchase and application costs of LSFs are comparable to those for conventional fluxes. ***Elimination of the cleaning step results in economic benefits.*** The LSF applicator would be applicable to through-hole component circuit boards only, where fluxes are needed to promote wettability so that solder joints can be formed.

Benefits are as follows:

- Conversion to this technology is easy.
- LSFs eliminate the need for defluxing and for the use of solvents.
- Capital costs are low.

Limitations are as follows:

- Special equipment, such as an LSF applicator, may be required.
- Limited residues are unacceptable in many military specifications.
- Activity of LSFs is limited to a short dwell time.

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- ! Cleanliness requirements may be stricter for components and PC boards.

The AT&T plant in Columbus, Ohio, converted completely to an LSF system. The plant eliminated post-solder cleaning and the use of 30,000 gallons of perchloroethylene (PCE) annually. Using the flux applicator also reduced the amount of flux material product used by about 2,000 gallons per year. Cost savings at the plant are estimated at $145,000 per year as a result of the decreased need to purchase, treat, track, and report on this solvent.

Protective Coatings

Protective coatings can reduce the need for a flux, which can reduce the need for cleaning. Nonoxidizing surfaces, such as gold or other alloys, can be wetted by solder without fluxing. However, the thickness of a gold layer must be carefully controlled when using tin-based solder alloys, because gold and tin react to form a brittle intermetallic that could weaken a solder joint if excess gold is applied.

Conversely, a thin, porous layer of gold might expose the underlying metal to oxidation or corrosion in a poorly controlled storage environment. For this scenario, organic inhibitors are being developed that could be applied to the protective coatings to guard against oxidation. The combination of protective coatings and organic inhibitors may allow for fluxless soldering.

Alternative Solder Materials

Because the presence of lead in solder is an environmental concern, various lead-free solders have been investigated. One promising alternative is bismuth, a by-product of lead and copper refining. Another innovative approach is to replace metallurgical solders with a conductive adhesive. For solder replacement, silver-filled epoxies are typically used. A company must consider all process variables before replacing solders. ***However, replacing lead solders could eliminate the need for cleaning at this step, which could provide a considerable cost savings.***

CLEANING

Aqueous Cleaners

Aqueous cleaners are mixtures of water, detergents, and other additives that promote the removal of organic and inorganic contaminants from hard surfaces, rather than dissolving them in an organic solvent. Each component performs a distinct function and affects the way in which the contaminant is removed from the substrate.

Surfactants provide detergency by lowering the surface and interfacial tensions of the water so that the cleaner can better penetrate small spaces and lift contaminants from the substrate. Deflocculants help to maintain the dispersion of contaminant particles in the cleaning medium. Because many emulsions remain stable only at elevated temperatures and under alkaline conditions, separation of the oily fraction from the aqueous cleaner can often be induced by lowering temperature and acidifying the bath. Saponifiers react chemically with oils containing fatty acids (vegetable oils and animal fats) to form soaps. Coupled with saponifiers, surfactants can act as wetting agents to help to remove contaminants from the surface. Organic amines can react with many common hydrocarbon contaminants, including the saponifiable portion of solder flux rosin; however, organic amines are hazardous. Sequestering agents prevent the mineral content of hard water from forming insoluble products with the cleaner. Their use enables the cleaner to attack only the contaminant and ensures that lower cleaner concentrations are needed.

In aqueous cleaning, alkalis, deflocculants, and sequestering agents are referred to as builders. Anti-foaming agents and corrosion inhibitors may be added to enhance the performance of builders. Corrosion inhibitors either passivate the surface by adsorbing onto it a molecular species that will (1) react with oxygen before the metal can oxidize, or (2) form a protective barrier over the surface that excludes oxygen. Drying methods include accelerated evaporation (hot air recirculation, evaporative drying), displacement (capillary or slow-pull drying), and mechanical removal (air knives, centrifugal drying). Primary detergents are used to process buffed metals at temperatures of at least 120ºF. Alkaline detergent cleaners are used to remove light oils and residues (including solvents or other types of cleaners) at elevated temperatures ranging from 120ºF to 200ºF.

Figure II-3 is a schematic diagram of an aqueous cleaning process.

Benefits of aqueous cleaners are as follows:

! Effectively remove inorganic/ionic contaminants, particulates, and films.

! Flexible in application and available cleaning methods.

! Performance can easily be enhanced by formulation, dilution, and temperature.

! Effectively remove most oils and greases.

! Contain few hazardous chemicals.

! Water can be recycled.

! Generally pose less risk to personnel and the environment.

Limitations of aqueous cleaners are as follows:

! Compatibility with some materials is limited, possibly leading to metal corrosion or stress corrosion cracking.

! Use may require drying of parts or components.

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! Wastewater treatment is necessary to mitigate human and environmental risks following disposal.

Semiaqueous Cleaners

Semiaqueous cleaners comprise a group of cleaning solutions that are composed of natural or synthetic organic solvents, surfactants, corrosion inhibitors, and other additives. The term "semiaqueous" refers to the use of water in some parts of the cleaning process, such as washing and rinsing. Semiaqueous cleaners are designed to be used in process equipment designed for aqueous cleaners. Commonly used semiaqueous cleaners include water-immiscible types (terpenes, high-molecular-weight esters, petroleum hydrocarbons, and glycol ethers) and water-miscible types (low-molecular-weight alcohols, ketones, esters, and organic amines).

Figure II-4 is a schematic diagram of a semiaqueous cleaning process. Figure II-5 is a schematic diagram of a typical piece of spray equipment used to apply semiaqueous cleaners. Terpenes are natural hydrocarbons derived from plant sources such as citrus and pine oils. Types of terpenes include d-limonene, a- and b-pinene, and para-menthadienes. In water, terpenes form emulsions if they are stabilized by surfactants and other additives. In cleaning applications, terpenes may be diluted for use on less difficult contaminants. Dilution reduces cleaning performance but decreases usage, reduces expense, and lowers vapor pressure, thereby decreasing vapor emissions.

Esters have good solvent properties and are soluble in most organic compounds. High-molecular-weight esters have limited solubility in water, but may be used—either cold or heated—to improve cleaning performance. Types of high-molecular-weight esters that are most commonly used in cleaning include aliphatic mono-esters and dibasic acid esters. Among the low-molecular-weight esters, which are water-soluble, ethyl lactate is reported to have good cleaning, health, and safety properties. Ethyl lactate is a VOC, with a moderate flash point of 126^{o}F.

Glycol ethers have good solvent properties and are soluble in most organic compounds, but they pose a health risk. They form emulsions with water that can be separated for recycling. N-methyl-2-pyrrolidone (NMP) is completely miscible with water and organic compounds, and can be used—cold or heated—because of its high flash point (about 199^{o}F). Also, NMP is effective for cleaning at dilute concentrations.

Semiaqueous cleaners are designed to be water-rinsable and nonwater-rinsable. After being washed in a water-rinsable cleaner, cleaned parts may be rinsed in water to remove residue. Parts cleaned with a nonwater-rinsable cleaner are rinsed in a secondary tank with alcohol or other organic solvent to capture drag-out cleaner, which is residual cleaner carried over from the previous tank. Several technologies enable separation of semiaqueous cleaners from the wastewater to be recycled or discharged for treatment.

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Proper use of these cleaners is required to reap their full pollution prevention benefits. Good engineering design is essential so that air emissions can be kept low. Examples of good engineering design are as follows:

- Operation of the cleaning bath at the minimum temperature at which acceptable cleaning performance is obtained
- Use of low-vapor-pressure cleaning agents
- Minimization of dragout by using air knives
- Maintenance of the air exhaust rate at a minimum level

In general, semiaqueous cleaners have excellent solvency for numerous difficult contaminants, such as heavy grease, tar, and waxes. The cleaners have low surface tension, which decreases their contact angles and enables them to penetrate small spaces, such as crevices, blind holes, and below-surface-mounted electronic components. As with aqueous cleaners, rinsing is necessary to avoid leaving a residue on the cleaned parts. If they are rinsed with water, the parts must be dried. If a volatile organic solvent, such as alcohol, is used to rinse the parts, drying will be accelerated. Semiaqueous cleaners are widely available. Drum-sized quantities are typically priced from $10 to $20 per gallon for terpenes, esters, and glycols, and from $25 to $30 per gallon for NMP.

Advantages of semiaqueous cleaners over aqueous cleaners include the following:

- More aggressive in removing heavy organic contaminants
- Lower corrosion potential with water-sensitive metals and most plastics
- Easier penetration of small spaces, because of lower surface tensions
- Biodegradability, which facilitates direct discharge of diluted semiaqueous cleaners to the sewer system

Limitations include health concerns and low flash points. Mists of concentrated semiaqueous cleaners can be ignited at room temperature, which can restrict safe operating temperatures in some cases. Washing equipment should be designed to avoid creating mists, such as by spraying or agitating below the fluid surface or by using ultrasonic action. Potential concerns associated with the improper or uncontrolled handling of semiaqueous cleaners include health-related problems, strong odors, and toxicity.

The primary pollution prevention benefit of semiaqueous cleaners is that they do not deplete the stratospheric ozone layer. These cleaners are also biodegradable but may require add-on treatment in older industrial wastewater treatment systems. A batch-type or continuous-flow fixed-film biological reactor is recommended to process rinse water from semiaqueous cleaning to increase residence time and effect complete degradation.

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ETCHING AND PHOTORESIST

Dry Film Resist

Early types of photoresist used to create patterns on PC boards required the use of chlorinated solvents to first develop, and then strip, the coating. A newer process, termed "dry film resist," is mechanically laminated to the PC board, and the image is transferred by exposure to UV light through a mask outlining the patterns of the circuitry. This type of resist can then be stripped in various semiaqueous solutions, which can be discharged to the municipal wastewater treatment plant with minimal filtration and monitoring. ***Changing to this type of resist will enable a company to significantly reduce the use of chlorinated solvents and still produce PC boards that are more sophisticated.*** However, operating costs are currently higher than those for the traditional silkscreening process.

Alkaline Permanganate Desmear and Etchback

After holes are drilled in a PC board, two other operations may be needed. One is desmearing, which is the removal of friction-melted epoxy resin and drilling debris from the holes. The other is etchback, which is the removal of epoxy polymer, especially between the layers of a multilayer board. Common materials used for these processes include chromic acid and concentrated sulfuric acid, which have high process costs because of waste treatment requirements. An alternative solution for both desmearing and etchback, based on the reduction of permanganate, has the advantage of operating in a closed loop by using regeneration. An oxidizer is added as needed to restore the permanganate concentration; occasionally, the solution can be chilled to recover the waste, which consists of crystals of manganese oxide. Processing experience shows excellent solution life and performance, but it is usable only with specific types of board materials, such as epoxy and polyimide.

Source Reduction through Process Changes

FLUXING AND SOLDERING

Fluxless and No-Clean Soldering

An inert soldering atmosphere can eliminate the need for flux and, consequently, for cleaning (no-clean soldering). Without the cleaning process, solvents are not needed. Because reoxidation of exposed surfaces during reflow is a major cause of poor soldering, one solution is to eliminate oxygen. Because of its availability and low cost, nitrogen is often used.

Benefits of no-clean soldering are as follows:

- Eliminating flux eliminates the need for cleaning.
- Eliminating use of both flux and cleaning results in a simpler process, thereby resulting in economic and process time savings.
- Eliminating flux also eliminates any flux residue, which may cause reliability problems.

- Solder loss may be reduced.

Limitations of no-clean soldering are as follows:

- Tighter control and higher precision are required in the reflow process.
- Slightly higher skill level is required for operation.
- It requires an initial capital outlay for a new furnace.

No-clean fluxes can be applied without special methods, resulting in significantly reduced flux residues; however, even small amounts of residue may affect product performance. No-clean fluxes are often used in combination with various clean or reducing atmospheres to maintain or produce a solderable base surface. Inert or reducing gases, reactive plasmas, and activated acid vapors have been used to create atmospheres that restrict the supply of oxygen to the workpiece during heating and soldering operations. When controlled atmospheres are used with LSFs, the flux residues are usually negligible.

One fluxless soldering process uses nitrogen-controlled reflow soldering machines with activators that are applied on the surface of the board. The activators are various acids (often formic or abietic acid). Because the oxygen content of the process is controlled, no oxides form on the boards, and the residues do not need to be cleaned up. This process should be thoroughly researched before it is incorporated into a production process, but it is a single-step process that eliminates the need for liquid cleaning systems.

CLEANING

Automated Aqueous Cleaning

Automated aqueous cleaners use aqueous cleaning solutions, instead of solvents, to achieve high-quality cleaning. ***This technology generates a waste stream that is less hazardous and reduces the amount of wastewater generated.*** The process removes some of the contamination that comes off of the components being cleaned into the cleaning solution. The cleaning solution can then be recirculated several times.

The automated aqueous washer sprays an aqueous solution across the components to remove residues or debris (Figure II-6). The components move through a series of chambers, each having a different concentration of cleaning and rinsing solution. Excess sprayed solution is recovered and reused. A typical unit consists of a series of five compartments through which the soiled metal

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parts are transported via a helical screw conveyor. The parts are sprayed successively with solutions from five holding tanks, one per compartment. The first compartment sprays hot water on the parts, which helps to break the residual machining fluids (oil-water emulsions). The second and third compartments spray two different concentrations of detergent solutions on the parts, followed by a clean water rinse in the fourth compartment. The fifth and final compartment sprays a rust inhibitor solution, if required. A dryer vaporizes any water droplets remaining on the parts. Used solutions are recirculated for a period of relatively continuous operation in a closed-loop system. Separator tanks separate oil and debris from the used solutions. Because recovery and reuse of the cleaning solution is automatic, the unit requires very little operator attention. The main features of this type of washer are (1) improved contact between the part surface and the cleaning solution, and (2) several recovery and reuse cycles of cleaning solution. Some new units claim zero wastewater discharge, with fresh water added only to compensate for evaporation in the dryer.

Benefits of automated aqueous cleaning are as follows:

! Improved contact between cleaning solution and parts being cleaned enables cleaning of most types of parts without solvents.

! Solvent use can be reduced or eliminated.

! Cleaning effectiveness is comparable to that of vapor degreasing or conventional aqueous cleaning processes.

! Amount of wastewater generated is lower than that generated by traditional processes.

! Installation and operation are easy; labor and skill requirements are low.

! Technology consumes less cleaning chemicals than traditional processes.

! Continuous operation enhances plant efficiency.

! Operating cost savings are realized.

Limitations of automated aqueous cleaning are as follows:

! Wastewater generated must be treated and discharged.

! Some types of parts cannot be cleaned as effectively.

! Because of drying, energy requirement is high.

! Initial capital cost is relatively high.

! Drying can leave spots if rinsing is inadequate or rinse water contains a high level of dissolved solids.

Laser Cleaning

Laser cleaning involves the use of short pulses of high-peak-power radiation to rapidly heat and vaporize thin layers of material surfaces. The vapors are removed by being entrained into a flowing gas stream before they can recondense and recontaminate the material surface. On a nonmetallic surface, such as that of a semiconductor, the primary contaminants are oxide films and absorbed metal ions. Over the past 25 years, ruby, alezandrite, and carbon dioxide (CO_2) lasers have been used for cleaning; however, more recently, excimer lasers have been used for laser cleaning of semiconductor substrates.

Laser ablation is the mechanism involved during laser cleaning of semiconductor substrates. Laser ablation vaporizes thin layers of contaminants at the air-contaminant interface. Efficient use requires that the contaminant be strongly absorbing at the laser wavelength. Consequently, UV lasers, such as krypton-fluoride (KrF) excimers, have been used most for this cleaning application. UV wavelengths can clean more efficiently than other laser wavelengths because the absorption depth into oxides is much smaller (about 10 nanometers [nm]) in the UV region.

Liquid-assisted laser cleaning is a variation in the use of lasers for cleaning. In microfabrication of semiconductor devices, residual micron-size particles cause defects on the same scale as that of the microstructure being produced in the process. These micron-size particles are extremely difficult to remove, because the binding forces (Van der Waals, capillary, and electrostatic) that hold them on the surface are much greater than the gravitational and inertial forces at this particle size. Benign-liquid-assisted laser-cleaning techniques successfully achieve particulate removal without the use of Freon™ (CFC-113) or harsh solvents.

One technique, developed at IBM, involves forming a very thin volatile liquid layer (water, ethanol, methanol, isopropanol, and mixtures thereof) on the surface to be cleaned immediately before delivery of a short laser pulse. The liquid works its way under the particles by capillary action and is explosively evaporated by conduction of heat from the substrate, which is heated directly by the laser pulse. At IBM, the process was conducted on silicon surfaces exposed to 16-nanosecond laser pulses from a KrF excimer laser (0.248 micrometer wavelength). The process is a dry-cleaning process because of the short residence time of the liquid on the surface. In a slightly different approach, micron- and submicron-sized particles were cleaned from silicon substrates by using a laser wavelength that is absorbed directly with the liquid deposited as the assist layer rather than in the substrate itself. Water was found to be the best liquid, and the CO_2 TEA laser (100-nanosecond pulse, 1 microsecond tail) with 9.6- and 10.6-micrometer wavelength was used.

Benefits of laser cleaning include the following:

- Area to be cleaned can be highly selective and sharply defined.
- Process is generally very fast and energy efficient.
- No foreign atoms are introduced to the surface as they are in ion bombardment

techniques.

- If cleaning is performed in a vacuum, the vacuum is not compromised, because the laser source can be located outside of the cleaning chamber.

- Thermal diffusion of bulk impurities to the surface is avoided because of the extremely large quenching rate afforded by the very short pulses that are available.

- The removal rate can be easily controlled by changing the beam fluence or pulse repetition rate.

- Laser cleaning is amenable to "dry" effluent control through cover gas filtering.

- Liquid-assisted laser cleaning removes micron-sized particles.

Limitations of laser cleaning include the following:

- Laser cleaning requires a special cleaning chamber.

- Laser energy may damage some substrates.

Plasma Cleaning

Plasma cleaning is one type of surface processing, among several, that depends on production of a low-pressure steady-state plasma in a special vacuum chamber. These processes include ion plating, plasma-enhanced chemical vapor deposition, etching, cleaning, and surface modification. Plasma cleaning has a relatively low cleaning rate that is best used to remove thin contaminant films.

In typical plasma processing, the excitation of the gas may be from a direct current (DC), radiofrequency (RF), or microwave power source. If an inert gas is used, the ions and neutrals in the plasma bombard the surface to be cleaned and sputter off the contaminant in a purely physical manner, molecule by molecule. If a reactive gas is used in the plasma, the bombarding ions may also react with the contaminants and form gaseous species that evaporate from the surface.

Recent research indicates that plasma cleaning has value in cleaning PC boards. IBM researchers found that RF reactive cleaning with oxygen-carbon tetrafluoride may be used to remove epoxy/glass particle/copper drill smears in drilled through-holes in PC boards.

One benefit of plasma cleaning is that it can accomplish ultrafine cleaning. However, this type of cleaning (1) requires a special cleaning chamber and (2) is a relatively slow process.

Carbon Dioxide Snow

Gaseous or liquid CO_2 is drawn from a room-temperature gas cylinder or high-pressure dewar and expanded through a nozzle to produce fine CO_2 particles and CO_2 gas. These particles, which are dry ice "snowflakes," are propelled by the gas stream. When the gas or liquid is throttled through a special nozzle and expanded to form a jet, it undergoes a phase change into the solid state. The shape and size of the snowflakes depend on the configuration of the nozzle and the conditions in which the flake formed in the gas stream. The snowflakes can be individual crystals or collective groupings of crystallites.

Cleaning is performed when the snow particles affect a contaminated surface, dislodge adherent contaminant particles, and carry them away in the gas stream. ***The process is effective in removing very small (submicron) particles, in which fluid drag typically restricts the performance of liquid phase cleaning.*** The CO_2 snow cleaning process is also believed to attach hydrocarbon film by dissolving hydrocarbon molecules in a temporal liquid CO_2 phase at the film-substrate interface. The dissolved film is then carried away by the subsequent flow of snow and gas.

CO_2 snow gently removes particles, ranging from smaller than 10 microns in diameter to 0.1 micron, that are difficult to remove by using high-velocity liquid nitrogen. It is used to remove light oils and fingerprints from mirrors, lenses, and other delicate surfaces, and from precision assemblies, without scratching the surface. ***CO_2 snow can clean hybrid circuitry and integrated circuits without disturbing the bonding wires. No other cleaning mechanism can duplicate this unique ability.*** In the disk drive industry, CO_2 snow is used to remove particles from disks without damage to the operation. If the dust or dirt particles removed by the snow are a hazard, they can be collected by an electrically charged curtain.

The process is used to remove paste fluxes in soldering. If the grease cannot be removed with the snow, a combination of CO_2 snow and ethyl alcohol is effective, followed by CO_2 snow alone to remove the impurities from the alcohol.

CO_2 is used to remove hydrocarbons and silicone grease strains from silicon wafers. Wafers that were artificially contaminated with a fingerprint, a nose print, and a thin silicone grease film were found to have surface hydrocarbon levels that were 25 to 30 percent lower after CO_2 snow cleaning than those of the original wafer surfaces. Reportedly, high-velocity CO_2 snow reduced zinc orthosilicates and other particles—ranging from 0.1 to 0.5 micron in diameter—on a silicon wafer by more than 99.9 percent.

A complete system includes a CO_2 purifier, a pneumatic-actuated head, and a microprocessor-based timing circuit. Several models of manual spray booths are available that provide a nitrogen-purged, heated, and monitored environment for CO_2 spraying costing from $10,000 to $15,000.
CO_2 snow has the following benefits:

! It performs ultrapure cleaning of light oils down to submicron size on the most delicate and sensitive materials, ranging from bonding wires to precision mirrors in telescopes.

! It adjusts to a wide range of size and intensity.

! It does not create thermal shock, is nonflammable and nontoxic, and causes no undesirable chemical reactions.

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- It is noncorrosive and leaves no residue.

- No media separation system is required; there is no media disposal cost.

- It penetrates nonturbulent areas to dislodge contaminants without disassembly.

CO_2 snow has the following limitations:

- Heavier oils may require chemical precleaning and/or heating.

- CO_2 must be purified, resulting in an added expense, because of its tendency to dissolve contaminants from the walls of tanks in which it is stored.

- Because of long dwell times, airborne impurities may condense on excessively chilled surfaces.

- Although CO_2 snow will not scratch most metals and glasses, hard particulates on a surface may cause scratching when they become airborne (carried by the gas stream).

Catalytic Wet Oxidation Cleaning

Catalytic wet oxidation is a proposed method for chemically oxidizing, or "burning," organic contaminants within an aqueous medium. Oxygen-rich air pumped into an aqueous solution can be used to gasify organics that adhere to a substrate, thereby converting them to more easily biodegradable chemical intermediates. ***In principle, the final waste products are CO_2 and water, and the process consumes little energy.***

The process works by forming water-soluble intermediates as organic materials are broken down into smaller molecular species. Catalysts—such as iron (III)/iron (II) salts—and cocatalysts—such as platinum (IV), ruthenium (III), rhodium (III), cobalt (II), or vanadium (V) complex—are used to increase the rate of wet oxidation reaction. Polymerization sometimes occurs, as in the formation of gums in petroleum oils. High temperatures (250°C to 300°C) may be required to obtain nearly complete conversion of organic matter with the wet oxidation technology.

A benefit of catalytic wet oxidation cleaning is that it can be used to clean wet parts. However, this cleaning technology may damage or corrode some substrates.

PHOTORESIST

Photoresist waste generated in semiconductor fabrication (1) is extremely expensive as a virgin chemical (about $300 to $400 per gallon) and (2) has high disposal costs, often requiring Class I hazardous waste landfilling or incineration. When photoresist is dispensed onto the crystal wafers by a spinner, supply bottles of photoresist are often monitored and changed manually by an operator. Because the operator tries to avoid having empty supply bottles, there is usually residual photoresist, which is collected and managed as a waste. In one facility, this resulted in the generation of almost 4 gallons of waste per week.

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An automated photoresist dispensing system uses a holding tank and pumping system to completely empty each supply bottle. ***At one facility, the savings realized by this system reduced purchases of photoresist by $54,000 annually, for a payback period of 7 months.***

Source Reduction through Improved Operating Practices

Training

Employee training is often discussed but is typically difficult to administer. However, in any operation that requires manual transfer of parts between process tanks, there are many pollution prevention opportunities. An increase of drain time to 10 seconds during electroless copper plating of PC boards has been shown to reduce solution loss and, therefore, waste generated in that process line, by as much as 40 percent.

Any facility will benefit from an optimal training program. Training is needed especially when a company is changing its production processes. ***One example of a group that provides hands-on training is the Electronics Manufacturing Learning Center (EMLC) in Indianapolis, Indiana (317/226-5607). The EMLC is part of the Electronics Manufacturing Productivity Facility (EMPF), which is a National Center of Excellence for electronics manufacturing dedicated to transferring state-of-the-art manufacturing technologies to companies of all sizes.*** EMLC's *Low-Residue/No-Clean Soldering Process Implementation* is one example of a course that may assist a company's pollution prevention program. EMLC and its parent organization, EMPF, offer a variety of technical information to electronics manufacturing companies.

On-Site Reuse and Recycling

Efforts to reuse process materials in the electronics industry are complicated by the high purity that is often required. Semiconductor processing is particularly exacting, requiring a clean room environment at most stages. The technology required to achieve these levels of purity is often unavailable on site. Etching and solvents are two significant process areas of waste generation in which reuse and recycling have shown promise.

ETCHING

After the pattern of circuitry on a PC board has been covered with a layer, termed the "etch resist," the photoresist covering the rest of the board is stripped away, exposing bare copper. The next production step is to etch away the bare copper, leaving a web of circuits. The etch resist protects these circuits during the etching process—which in 74 percent of all PC board production facilities—is accomplished with an ammonia-based solution. These etchants have wide compatibility with resists and remove copper very quickly, but they can pose problems for some waste treatment systems and do not lend themselves well to metal recovery and regeneration. An alternative, which is used in over 20 percent of these facilities, is a solution of hydrogen peroxide and sulfuric acid.

This etchant is operated continuously by replenishing it with hydrogen peroxide and sulfuric acid while

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building copper to the appropriate concentration. The etchant is then cooled, and copper sulfate pentahydrate crystals are recovered. The etchant is then replenished and returned to use.

Limitations of this etchant are (1) relatively slower etch rates, important for high-production facilities, (2) incompatibility with some types of resists, and (3) a reaction chemistry that is highly exothermic without careful temperature maintenance. Another etchant, which is based on nitric acid modified with copper nitrite and/or sulfuric acid, shows similar recovery potential with a higher etch rate, but has limited application.

SOLVENTS

NMP

NMP, which is used to strip polyimide used as a passivator between layers on the wafer, is a commonly used solvent in the fabrication of semiconductor wafers. Because fabrication of semiconductor devices requires that several layers be coated with polyimide and stripped, substantial quantities of the solvent may be used. Although it is marketed as being biodegradable, at a cost of about $25 to $30 per gallon, there is considerable economic incentive for recycling. The stream of waste solvent consists of NMP with small amounts of polyimide and water. To be satisfactory for reuse, the water and polyimide must be removed with a required NMP purity of 99.5 percent and nondetectable turbidity. Water from the waste stream is evaporated under vacuum and discharged for on-site treatment. The NMP-polyimide mixture is boiled, thereby enabling separation of the NMP by flash distillation. Polyimide is accumulated for sale or reclaim.

ELECTROLESS COPPER ELECTROPLATING

Metal Recovery

Chemicals are frequently added to electroless copper plating solutions to maintain proper chemical concentrations, resulting in a bath that continually grows in volume. This increased volume, which is known as bath growth, poses treatment problems because of high metal concentrations and chelates. One PC board facility uses a system that recovers copper as metal plated onto carbon granules, which yields a solution suitable for sewer discharge. At this facility, bath growth totals over 1,000 gallons annually, which—when treated with precipitation methods—yield about 1,000 pounds of sludge. The recovery system adjusts chemical concentrations to optimize the reaction, and then passes the solution through two identical reactors charged with treated carbon, using low-shear agitation to fully use the surface area of the carbon. Seven pounds of this carbon recover 17 pounds of copper for reclamation.

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Chapter 3

The Macroelectronics Industry

This chapter focuses on the manufacturing of electronic products for consumers. The chapter is divided into the following three sections: Macroelectronics Products, Processes and Typical Waste Streams, and Pollution Prevention Options for the Macroelectronics Industry. Macroelectronic Products introduces the general categories of products that this chapter will cover. As the products are introduced, the general processes used to manufacture these products will also be presented. Processes and Typical Waste Streams presents more detail on specific steps of the manufacturing processes that can be targeted for pollution prevention. The manufacturing processes associated with different macroelectronic products often share similar process steps; for example, metal fabrication is important for the manufacturing of many macroelectronic products. For this reason, the second and third subsections will be organized around categories of process steps instead of categories of products. This enables the authors to present the material with minimal duplication. Pollution Prevention Options for the Macroelectronics Industry focuses on methods of reducing generation of waste in the processes detailed in the second subsection.

MACROELECTRONICS PRODUCTS

The macroelectronics industry is involved in the (1) assembly of microelectronic components into larger electronics products, and (2) fabrication of the macroelectronic product housing. Metal fabrication plays a significant role in the macroelectronics industry, especially in the manufacture of housing for computers and electronics appliances. Fabricated metal products undergo various processes, including machining, stripping, cleaning, plating, coating, and painting. Wire and cable are integral parts of the electronics industry, and must be functional over a wide range of applications in addition to transmission of electrical power. For the purposes of this manual, the macroelectronics industry is defined as comprising facilities involved in manufacturing final electronics products, including computers, electric motors, electronic appliances, televisions, stereo electronics, lighting equipment, and wire harness assemblies.

PROCESSES AND TYPICAL WASTE STREAMS

Machining Operations

Machining operations involve various cutting processes including drilling, threading, grinding, and polishing. These processes use cutting tools, the energy of which is transformed into heat. In the case of metal products, metalworking fluids are applied to facilitate the cutting operation. A metalworking fluid is used to (1) lower tool and workpiece temperatures, (2) provide a good finish on the workpiece, (3) wash away metal chips, (4) inhibit corrosion or surface oxidation of the workpiece, and (5) lubricate

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the tool-workpiece interface.

Metalworking fluids include water (either plain or containing an alkali); emulsions of a soluble oil or paste; and "straight" oils (those that are not water-based), such as mineral, sulphurized, or chlorinated oil. These fluids can be air-blasted, sprayed, or drawn through suction onto the tool-workpiece interface.

Parts Stripping and Cleaning

Stripping and cleaning operations are integral to numerous processes in industries involved in the manufacture of metal and macroelectronic parts and equipment. Stripping is used as the first step in reworking off-specification products.

Abrasive blasting is currently used to remove paints and other organic coatings from metallic and nonmetallic surfaces. Blasting media are composed of sand, glass, plastic, and steel shot. This method is generally used on large stationary workpieces or small pieces that cannot withstand heat or chemical stripping.

In manual grinding processes, hand or power tools—which abrade, cut, or scrape away the film—are used to remove tenaciously adherent organic or inorganic coatings.

Chemical stripping processes remove the organic coatings by direct application of chemicals, such as solvents, to the coated surface. These processes are used when the workpiece is uneven, has many small crevices, or is not amenable to mechanical removal.

Cleaning requires the removal of contaminants such as oil, grease, grit, and chips. The process prepares the product for further treatment, such as painting or plating, by affording better adhesive properties and increasing the quality of the finish. Solvent cleaning removes contaminants from metal parts with chlorinated solvents through spraying, wiping, vapor degreasing, or immersion. Semiaqueous cleaning uses organic solvents and water in a series of tanks. The part is first cleaned in a pure organic solvent to dissolve the soils, then rinsed with water to remove any residual soil and solvent. Aqueous cleaning uses a water-based cleaning solution that ranges from pure water to combinations of water, detergents, saponifiers, surfactants, corrosion inhibitors, and other special additives.

Inorganic Surface Treatment and Finishing

Inorganic surface treatment and plating operations involve altering the surface properties of a workpiece to increase corrosion or abrasion resistance, alter appearance, or otherwise enhance the utility of the product. Inorganic surface treatment includes chemical and electrochemical conversion, case hardening, metallic coating, and chemical coating. Plating operations include electroplating and electroless plating processes.

Chemical and electrochemical conversion treatments include phosphating, chromating, anodizing, passivation, and metal coloring. Phosphating treatments provide a coating of insoluble metal phosphate crystals that adhere strongly to the base metal and provide some corrosion resistance and provide a base for adhesion of paints, lacquers, and oils. Chromate coatings are applied to minimize rust formation and to guarantee paint adhesion. Anodizing is used to develop a surface oxide film on the workpiece to enhance its resistance to corrosion. Passivation forms a protective film on the part surface through immersion in an acid solution.

Case hardening produces a hard surface (the case) over a metal core that remains relatively soft. The case is wear-resistant and durable, whereas the core remains strong and ductile. Case hardening methodologies include carburizing, carbonitriding, nitriding, microcasing, and hardening by using localized heating and quenching operations. Nitriding processes diffuse nascent nitrogen into a steel surface to produce case hardening by using either a nitrogenous gas (ammonia) or a liquid salt bath of sodium cyanide and potassium cyanide. Carbonitriding and cyaniding involve the diffusion of carbon and nitrogen simultaneously into the steel surface. Electromagnetic induction, high-temperature flames, and high-velocity combustion product gases can also be used to generate a case without chemicals.

Metallic coatings provide a durable, corrosion-resistant protective layer that is applied by hot dipping, spraying, cladding, or vapor deposition and vacuum coating. Common coating materials include aluminum, lead, tin, zinc, and combinations thereof.

Electroplating is achieved by passing an electric current through a solution containing dissolved metal ions and the metal object that is to be plated. Ferrous and nonferrous metal objects are typically electroplated with aluminum, brass, bronze, cadmium, chromium, copper, gold, iron, lead, nickel, platinum, silver, tin, and zinc. Electroless plating involves the deposition of metal on a metallic or nonmetallic surface without using external electrical energy.

Inorganic surface finishing improves the quality of metals by decreasing corrosion, oxidation, and wear; in some cases, it also provides decoration. The coating is usually applied via electroplating, cladding, anodizing, case hardening, or dipping.

Painting

After the metal surface has been prepared, it is painted, usually by using a conventional spray gun. This type of spray gun uses high air pressure to atomize paint. Conventional spray guns give a high-quality finish that is easy to apply. However, conventional spray guns produce a large amount of overspray, resulting in wasted paint and, for organic solvent-based paints, high VOC emissions. Painting operations are often conducted in spray booths to control overspray. Some spray booths have dry filters, and others use cascading water to capture excess paint and emissions.

Wire and Cable Manufacturing

The wire and cable industry has kept pace with advances in electronics by developing a wide variety of products—such as flat ribbon, coaxial, and fiber optic cable—that are functional over a wide range of applications. Conductor materials for wire and cable cores include copper, copper-coated steel, silver, nickel, and high-strength copper alloys; fiber optic cable has a silica glass or plastic core. In electronics applications, copper wire is usually plated with tin, silver, or nickel to improve solderability and inhibit corrosion. High-strength copper alloys—such as cadmium copper, chromium copper, and cadmium-chromium copper—are used in military and aerospace applications.

Conductive wires are usually coated with insulation materials. Primary insulation—applied directly onto the conductor—can be manufactured from rubber, synthetic polymers, nylon, polyvinyl chloride (PVC), fluorocarbon resins (Teflon), polypropylene, elastomers, or polyethylene (PE). Secondary insulation, or wire jackets and sheaths, are made from extrudable plastics, rubber, neoprene, nylon, silicone, PVC, or Teflon. Wire harness assemblies are bundles of insulated conductors that have been bound together to permit multiple breakouts (diverted to complete intermediate circuits along the main cable route).

Waste streams associated with wire and cable manufacturing and applications include scrap metal and insulation materials.

Mercury Usage in the Macroelectronics Industry

The quantity of mercury used in electronic applications is significant. The macroelectronics industry, especially companies that are involved in manufacturing electrical lighting and electrical control and switching devices, has not found a suitable substitute for mercury and mercury compounds, because of the unique electromechanical and photoelectric properties of mercury.

Mercury-containing lamps include fluorescent lamps and high-intensity discharge (HID) lamps (mercury vapor, metal halide, and high-pressure sodium lamps). Mercury acts as a multiphoton source in fluorescent lamps. The mercury content typically ranges from 20 to 50 milligrams per tube, depending on the size. Although manufacturers are working to reduce the mercury content of each lamp, increased use of fluorescent lamps is expected because of their energy efficiency. By the year 2000, mercury contamination resulting from the disposal of fluorescent lamps as municipal solid waste is projected to increase to 37.1 metric tons. Industrial and economic data indicate that the quantity of mercury used in electronic control devices—switching devices, thermostats, circuit control relays, and manometers—is significant. Of the 70 million thermostats in residential use today in the United States, an estimated 90 percent contain mercury.

Display Screens

The display screen is one of the most critical, and most volume-intensive, components of computer systems. Because of its low cost per pixel and high-quality display, the predominant display technology is the cathode ray tube (CRT). In the U.S., CRTs are produced mainly for the color-television industry and monochrome industrial, military, and computer industries. The CRT display is composed of a glass panel, a CRT, a casing, various connectors, wiring, shielding, and a deflection yoke.

Advances in new display technologies are helping to position flat panel displays (FPD) as viable alternatives to CRTs, particularly in applications in which size, weight, or portability are concerns. There are many technologies that produce FPDs, including plasma display panels, electroluminescent displays, field emission displays, and active matrix liquid crystal displays. Processes common among

FPD manufacturers include photolithography, deposition, metallization, cleaning, sealing and encapsulation, clean room environments, and deionized water usage.

Typical Waste Streams and Waste Management Practices

Machining operations generate numerous wastes, including spoiled or contaminated metalworking fluids, and cuttings and other scrap metal. Contaminated metalworking fluids are treated as hazardous wastes because of their oil content, in addition to the presence of other chemical additives, such as chlorine, sulfur and phosphorus compounds, phenols, creosols, and alkalis. Spent metalworking fluids are currently either disposed of or recycled onsite and offsite. Recycling typically consists of separating the oils, through such methods as centrifuging, and refining them or using them as fuel. Metal fabrication also generates cuttings and other scrap metal. Scrap that is destined for reclamation is not regulated as hazardous waste. However, if metal chips are mixed with hazardous metalworking fluid wastes, the waste stream is treated as hazardous.

The types of wastes generated by stripping and cleaning parts depends on the cleaning medium, the type of substrate, and the type of soil removed. Table II-2 lists the stripping and cleaning wastes. If a facility has a wastewater treatment system, rinse water may be mixed with alkaline and acid cleaning solutions to undergo neutralization prior to treatment. Solvent waste may be sent to an off-site recycler or recycled onsite. For facilities that use small amounts of cleaner, the tendency is to drum the material for disposal.

Common surface treatment process wastes include spent acid and alkaline cleaning solutions, rinse waters, spent plating solutions, and filter sludges (Table II-2). On a volume basis, contaminated rinse water accounts for most plating process waste. Some or all of the waste streams may be combined into a single stream before treatment and disposal. Wastewater produced in an electroplating process may contain a variety of heavy metals and cyanide, which are typically precipitated under alkaline pH. The resulting metal sludge is thickened and disposed of by landfilling.

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TABLE II-2

TYPICAL WASTES GENERATED IN THE MACROELECTRONICS INDUSTRY

Waste Description	Generating Process	Waste Composition
	Metal Parts Cleaning	
Abrasive	! Removal of rust ! Scale polishing of metal	! Aluminum oxide ! Silica metal ! Grease
Solvents	! Removal of oil-based soils	! Halogenated solvents ! Nonhalogenated solvents ! Oil-based contaminants
Alkalines	! Removal of organic soils ! Descaling	! Alkaline salts ! Chemical additives ! Organic soils
Acids	! Removal of scale and smut	! Spent acids ! Chemical additives ! Dissolved metal salt
Rinse water	! Removal of cleaning material	! Water contaminated with cleaners and chemical additives
	Surface Treatment	
Spent process solutions	! Plating and chemical conversion	! Metal cyanides ! Spent acids ! Metal hydroxides ! Metal carbonates ! Ammonia
Filter sludges	! Plating and chemical conversion	! Silica ! Silicides ! Carbides ! Plating bath constituents
Quench oils	! Case hardening	! Oils ! Metal fines ! Combustion products
Wastewater treatment sludge	! Wastewater treatment	! Metal hydroxides ! Metal sulfides ! Metal carbonates
Vent scrubber wastes	! Vent scrubbing	! Metal cyanides ! Spent acids ! Metal hydroxides ! Metal carbonates ! Ammonia
Ion exchange resin reagents	! Demineralization of process water	! Brine ! Hydrochloric acid ! Sodium hydroxide

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Most paint coatings for fabricated metal products are solvent-based, generating large amounts of VOC emissions. These VOC emissions result in costly vapor recovery or treatment systems. Other paint wastes include empty paint containers, spent cleaning solutions, paint overspray, spent stripping solutions, and equipment cleaning wastes.

Mercury-containing wastes are generated during manufacture, assembly, and disposal of electrical lighting, mercury switches, and other electronic components. The wastes may contain phenolic resins and paper insulating materials mixed with soil.

The end-of-life disposal of CRT displays is problematic because of the limited cost-effective disposal options for leaded glass, mixed plastics, and other components of the display. Waste streams associated with the manufacture of FPDs are similar to those that are generated during fabrication of microelectronics.

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POLLUTION PREVENTION OPTIONS FOR THE MACROELECTRONICS INDUSTRY

Source Reduction through Material Changes

MACHINING OPERATIONS

Synthetic Metalworking Fluids

Synthetic metalworking fluids are composed of chemicals such as nitrites, nitrates, phosphates, and borates; they contain only 0 to 1 percent soluble oils, compared to 30 to 90 percent contained in nonsynthetic metalworking fluids. Synthetic fluids offer greater thermal stability at high temperatures, thereby resisting oxidation better than nonsynthetic fluids.

STRIPPING AND CLEANING

Many of the material changes and substitutions discussed as pollution prevention alternatives for the microelectronics industry can be readily applied to stripping and cleaning processes used during the manufacture and assembly of macroelectronics. These include replacing chlorinated solvents with organic nonchlorinated solvents, semiaqueous cleaners, and aqueous cleaners.

PAINTING

Alternative Coatings

The first alternative is to eliminate the need for painting. Much of the electronics industry already uses injection-molded plastic instead of painted metal cabinets.

Water-based coatings are paints that contain a substantial amount of water in place of the volatile solvent. Application is nearly identical to that of solvent spray systems, meaning that only minor equipment changes are required, and transfer efficiencies are the same. ***These similarities result in operating and capital costs that are similar to those of solvent spray or dip/flow systems.*** Another advantage is that water-based paints adhere well to aqueous-cleaned substrates, which could eliminate environmental problems in preparation steps. Overspray from a water-based coating can be collected or captured with water in the spray booth; the solution can then be concentrated and reused as paint. ***In addition to substantial reductions in environmental hazards, resulting from significantly lower air emission levels and smaller amounts of waste paint sludge generated, water-based coatings can provide energy savings by making it possible to recirculate the hot air used to cure the paint.*** The disadvantage of water-based coatings is their limited resistance to wear and corrosion on some steel and aluminum equipment and products.

High-solids solvent paints contain 50 percent or more solids by weight and have properties that are similar to those of solvent-based paints, thereby making substitution easy. The paints are applied at a high velocity by using conventional spray or electrostatic guns, which require no equipment changes.

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Because application equipment remains the same, capital and operating costs are unchanged. Because transfer efficiencies are not much greater than those of conventional spray methods, wastewater discharges and VOC emissions, though reduced, are still a problem. Also, high-solids solvent paints can require long drying times and provide nonuniform coatings, which can limit production capabilities.

Powder-coating systems are another alternative; however, they require the installation of new equipment. Powder-coating systems are discussed in the following section, ***Source Reduction through Process Changes***.

Source Reduction through Process Changes

CLEANING AND STRIPPING

Many of the process changes discussed as pollution prevention alternatives for the microelectronics industry can be readily applied to stripping and cleaning processes used during the manufacture and assembly of macroelectronics. These include improved aqueous and semiaqueous cleaning systems, plasma cleaning, and CO_2 snow.

Aqueous Power Washing

The aqueous power washer is a batch unit that is suitable for larger parts or a group of smaller parts. The parts are placed in a closed chamber on a turntable. As the turntable rotates, the parts are blasted from all angles with water and cleaning solution at high pressure (180 pounds per square inch [psi]) and elevated temperature (140°F to 240°F). The force of the spray jets, the heat, and the detergent combine to strip oil, grease, and carbon. The cycle time varies from 1 to 30 minutes, depending on the part and contamination. Used solution can be collected and sent through a filtration or sedimentation unit or other removal technology for reuse. Although most systems are simple single-compartment batch units, multiple-stage cleaning units or conveyorized automated systems are also available. Most units run on 220 volts of electrical power. An average unit may cost $12,000 and clean 1,000 pounds of parts per batch in 10 minutes with relatively low energy requirements.

Power washers are being used in a variety of industries to clean jet engines, electric motors, metal stampings, and diesel engines.

Aqueous power washing has the following benefits:

- Can replace solvent cleaning for many applications.
- Cleaning is more efficient than manual aqueous cleaning.
- Cleaning times are reduced.
- Involves a compact unit with a single chamber rather than several tanks or compartments.

! Small units are portable.

Aqueous power washing has the following limitations:

! Wastewater that is generated must be treated and discharged.

! Because of the high pressure and temperature, it is not suitable for more sensitive parts (electronic sensors and diaphragms).

! Jet washers may not remove baked-on dirt.

! Drying may leave spots if rinsing is inadequate or rinse water contains a high level of dissolved solids.

Ultrasonic Cleaning

Ultrasonic cleaning uses cavitation in an aqueous solution for greater cleaning effectiveness (Figure II-7). High-frequency sound waves generate zones of high and low pressures throughout the liquid cleaning solution. In the zones of negative pressure, the boiling point decreases, and microscopic vacuum bubbles are formed. As the sound waves move, this same zone becomes one of the positive pressures, thereby causing the bubbles to implode. This process is called cavitation. Cavitation exerts enormous pressures (10,000 psi) and temperatures (20,000°F on a microscopic scale), which loosen contaminants and perform the actual scrubbing of this cleaning process.

Ultrasonic cleaning involves three basic stages. During the first stage—presoak—the component is immersed in a heated cleaning solution to remove chemically soluble soil and gross contaminants. It is then scrubbed and cleaned through cavitation. In this stage, temperature is the most important factor. Increased temperature results in higher cavitation intensity and better cleaning; however, near the boiling point, the cleaning solution will boil in the negative areas of the sound waves, resulting in no effective cavitation. Other considerations include (1) cleaning solution concentration, (2) loading position and quantity of the parts, and (3) loading basket design. The final stage is rinsing of the cleaned part. In this stage, ultrasonics can be applied for increased efficiency.

The primary ultrasonic cleaning system has three components (Figure II-8): a liquid solution tank, an ultrasonic generator that supplies electrical energy, and a transducer that converts the electrical energy to mechanical energy. Most generators accept standard alternating current (AC) input at 60 hertz (Hz) and then convert it to DC. Sizes range from 200-watt tabletop units to large 1000-watt units. The optimum transducer frequency for most applications is about 20 kilohertz (kHz).

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Because microelectronics, such as PC boards, are fragile, 40-kHz equipment may be more applicable. Transducers can be bonded to the tank, or an immersible unit can be used. Immersible units are convenient when a transition is being made to ultrasonic cleaning and existing tanks are to be used.

Because of the simplicity of the equipment and the decreased cleaning time, use of ultrasonics results in a savings in labor costs. The efficiency of the technology also reduces or eliminates the need for strong solvents, although solvents can still be used with this technology. The savings in labor, and decreased solvent purchase and disposal costs, offsets the capital cost of the equipment in a short time. Although costs vary for specific equipment, the cost for an ultrasonic cleaner console with a 25-by-18-by-15-inch chamber is about $10,000. A rinse console and dryer console would add about $4,000 each. Smaller units can be obtained, and existing tanks can be retrofitted with the addition of a transducer.

Ultrasonic cleaning offers many other benefits:

- Reaches into crevices and small holes into which conventional methods may not reach
- Removes inorganic particles, in addition to oils
- Increases processing speed
- Reduces health hazards
- Uses lower, and possibly less toxic, concentrations of cleaning solution and fewer toxic agents
- Simple operation requires no special knowledge
- Decreases labor costs

Potential limitations include the following:

- Requires treatment and discharge of generated wastewater
- Requires that the part be immersible in the cleaning solution
- May require use of dryers after rinsing
- Requires testing to obtain the optimum combination of cleaning solution concentration and cavitation level
- Electrical power requirements for large tanks limit part sizes that can be cleaned economically
- Removal of thick oils and grease possibly limited by their tendency to absorb ultrasonic

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energy

! Requires closer monitoring of operating parameters

Vacuum Furnace Deoiling

A vacuum furnace uses heat and vacuum to vaporize oils from parts. Determining the optimum time and heat is based on the material properties (emissivity, cross-section, and mass), mass of the load, and vapor pressure of the oil contaminant. Most equipment is closed to eliminate emissions, and to facilitate backfilling the chamber with nitrogen and/or air to cool the parts before removal.
In a typical system, a load of parts is heated in a vacuum to vaporize all oils that are present. With newer designs, vapors are then condensed and collected for later removal to be reprocessed or recycled. Another recent design is a hot-wall design that eliminates furnace wall oil deposits caused by condensation. Temperatures range from 210°F to 650°F, and the vacuum range is 100/20,000 microns. A typical cycle time is about 15 to 20 minutes. Periodically, the operator must defrost the condenser and drain the oil for recycling, which is the only waste stream produced.

Vacuum furnaces can be applied where vapor degreasing is typically used to clean metal parts. Other applications include removal of paint solvents and precleaning for brazing, plating, or heat treating.

A comparison of vacuum furnace deoiling with vapor degreasing indicated that, although capital costs are higher for vacuum furnace deoiling, the estimated operating costs were lower, resulting in a payback of about 2 years for a 4000-hours-per-year operation. The capital cost for vacuum deoiling was nearly $200,000 for a system that will accept a workload with dimensions of 30 inches wide by 36 inches high by 48 inches long; the operating cost was an estimated $5.20 per hour.

Vacuum furnace deoiling provides the following benefits:

! Elimination of solvents prevents pollution.

! Elimination of solvents results in improved health and safety.

! Cleaned parts do not become water soaked and do not need drying.

Vacuum furnace deoiling has the following limitations:

! Processing time and temperature depend on material and oil; variability requires adjustments.

! Part must be able to withstand required temperature and vacuum pressure.

Supercritical Fluids Cleaning

The main advantage of using CO_2 as a supercritical fluid (SCF) is that it is nonpolluting and

derived from the atmosphere.

When CO_2 is compressed at above its critical pressure (73.7 bars, or 1077 psi), it becomes a critical fluid; when it is coupled with heating at above its critical temperature (31.1ºC, or 88.0ºF), it becomes a supercritical fluid. Critical and supercritical fluids are excellent solvents for dissolving many medium-molecular-weight, nonpolar or slightly polar organic compounds.

A typical SCF system consists of the following elements (Figure II-9):

- Compressed CO_2 source
- Chiller to condense CO_2 gas to liquid
- Pressure pump to elevate pressure
- Hot water bath to elevate line temperature to that of the cleaning chamber
- Cleaning chamber pressure reduction valve at fluid exit port
- Separator vessel to collect contaminants
- Air flow meter to monitor CO_2 usage

SCF cleaning is most effective in removing small amounts of soil from parts that require a high degree of cleanliness, such as gyroscope parts, accelerometers, thermal switches, electromechanical assemblies, and ceramics.

Capital costs are high, at least $100,000 for small-capacity equipment; however, the cost of CO_2 is about 7 cents per pound. SCF cleaning has been used in organic chemical analysis equipment and the defense industry.

SCF cleaning provides the following benefits:

- Low viscosity and high diffusivity permit cleaning within small cracks and pore spaces.
- Solvent power is pressure-dependent, which makes it possible to extract different soils selectively and precipitate them into collection vessels for analysis.
- It is compatible with metals, ceramics, and polymers (Teflon, epoxies, polyimides, high-density polyethylene).

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SCF cleaning has the following limitations:

- ! Potential rupture of pressure vessel or line endangers health and safety.

- ! It is incompatible with some polymers, acrylates, polycarbonate, neoprene, urethanes, and components that are sensitive to high pressures and temperatures.

- ! It is not effective in removing inorganic and polar organic soils, loose scale, or other particulates.

Absorbent Media Cleaning

Absorbent media can be used to remove grease and oil in situations in which aqueous and semiaqueous treatments cannot be used, as in the degreasing of water-sensitive materials or where lack of floor space makes rinsing impractical. Two types of absorbent media have been introduced to replace VOC-exempt solvents. One involves wiping with oil-absorbent wipers containing polypropylene fibers. The other uses various particulate absorbents, such as a natural silicates, wheat starch, and dry cellulose pulp.

The effectiveness of wipers depends on the surface size and viscosity of the grease or oil. Cheesecloth and specially produced wipers of fine texture have been used to remove fingerprints from mylar. Wipers of larger fiber dimension and rougher surface texture are used to sop up oil used during shop equipment maintenance and are effective on large, exposed surfaces. As part complexity increases and part size decreases, wipers containing thinner, finer fibers are required.

The new generation of wipers are made of recycled materials such as polypropylene. Because the fibers are not woven or coated, excess lint or shedding may occur. This problem can be resolved by designing a ventilation system to capture fugitive dusts. Spent wipers should be disposed of by recycling, incinerating, or landfilling, provided that they are not used to absorb toxic materials. Because polypropylene has high a British thermal unit (Btu) value, incineration may be a viable alternative.

Loose particulate absorbents are reportedly even more effective than wipers for removing grease and oil, because their surface area is greater and their impingement is better. They may also have a greater affinity for oil. Particulate absorbents include siliceous—such as talc, kaolin, and diatomaceous earth—and organic cellulose-based materials. Siliceous particulates visibly scratch aluminum surfaces and are unacceptable unless abrasive surface preparation is required. Of the organic absorbents tested, wheat starch performed best in terms of ease of use and results.

Starch cleaning involves dipping a foam-backed nylon bristle paint pad in the loose starch and using standard wipe techniques. The process waste—the oil-soaked starch aggregate—is vacuumed or swept away and can be sewered in many cases, depending on its toxicity and the wastewater characteristics of the oil. When it is sewered, the starch is useful as a feedstock for biological wastewater treatment plants. If the process grease or oil cannot be sewered, the process waste has Btu value for incineration. The nylon bristle pad can be reused many times. Therefore, the waste volume and handling requirements for starch are minimal.

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Starch has been shown to be more effective than cleaning with the solvent methyl ethyl ketone (MEK). In a test to compare cleaning of sesame oil, starch applied in one wiping cycle (five up-and-down scrubs) cleaned the oiled panels to a 99 percent level. Using fresh MEK in three successive wipes, replacing the wiper each time, achieved 96 percent cleaning of panels.

Absorbent cleaning was formerly regarded as a last resort substitution method. With starch, however, the material cost, shop time, safety, health, and environmental considerations outweigh the disadvantages for cleaning flat, exposed surfaces. A dust collection unit or vacuum table must be provided to prevent excess material from becoming airborne. When the surface is not too complex and dust collection is feasible, starch cleaning is a process improvement.

Add-On Controls To Existing Vapor Degreasers

The most common use of halogenated solvents is for vapor degreasing. ***As much as 90 percent of the solvent is lost because of air emissions and evaporation.*** Losses occur during (1) start-up as the solvent is heated and a vapor layer is established in the tank, (2) shutdown as the vapor layer cools and subsides, and (3) downtime when normal evaporation via diffusion occurs from the vapor layer. Significant losses also occur during workload handling in and out of the vapor degreaser.

Add-on control process changes include operating controls, covers, increased freeboard ratio, refrigerated freeboard coils, reduced room draft and lip exhaust velocities, changes in operating practices, and equipment modifications.

Low-Emission Vapor Degreasing (LEVD)

The LEVD, or completely enclosed vapor cleaning, is widely used in Europe, where vapor degreasers are regulated as a point source. As much as 90 percent of the solvent used in a conventional open-top vapor cleaner (OTVC) can be lost through air emissions. LEVDs, such as the one shown in Figure II-10, are commercially available in the U.S.

About 1 hour before a shift begins, a timer on the unit switches on the heat to the solvent sump. When the solvent in the sump reaches vapor temperature, the vapor is still confined to an enclosed jacket around the working chamber. Parts to be cleaned are placed in a basket and lowered into the working chamber through an opening in the top. After the lid has been shut, and the unit has been switched on, compressed air hermetically seals the lid shut for the entire cleaning cycle. Solvent vapors enter the sealed cleaning chamber from the outer jacket and condense on the parts. When the parts reach the temperature of the vapor, condensation is no longer possible. At this stage, fresh-vapor entry is stopped, and the air in the chamber is circulated over a cooling coil to condense out the solvent. Next, the carbon is heated to a temperature at which most of the solvent captured in the previous cleaning cycle can be desorbed, then condensed out with a chiller. The carbon adsorbs the residual solvent vapors from the air in the cleaning chamber. The adsorption stage continues until the solvent concentration in the chamber falls below a preset level (usually about 1 gram per cubic meter). After the concentration has fallen below the preset level, the seal on the lid is released, and the lid can be retracted to remove the cleaned parts. ***Only a very small amount of solvent exhausts at the end of the cycle when the lid is opened. The LEVD also works***

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as a distillation unit to clean the liquid solvent in the sump.

Advantages of the LEVD include the following:

- Minimizes idling losses or downtime losses during shutdown, unlike a conventional OTVC
- Operates as a distillation unit to reclaim used solvent
- Requires no operator attention, except to load and unload parts
- Minimizes solvent consumption
- Reduces air emissions by more than 99 percent from those of a conventional OTVC

Disadvantages of the LEVD include the following:

- Has a high initial capital cost (over $200,000)
- Requires a much larger cleaning-chamber capacity (or batch volume) to maintain the same processing rate as a conventional degreaser

There are other cost-benefit factors that should be considered. ***Using LEVD can result in savings in annual total operating costs of about $25,000, based on reduced labor costs (larger batch size) and lower solvent requirement (solvent recovery).*** Additional control devices for conventional degreasers—such as increased freeboard ratio, refrigerated coils, lip exhausts, and room ventilation—will add considerably to capital and operating costs. In contrast, the LEVD is a self-contained unit that will require no additional facility modifications to significantly reduce emissions.

Vapor Storage Technology

Vapor storage technology uses an air lock and airtight equipment to temporarily store solvent vapors from an existing vapor degreaser and return the vapors for reuse. The air lock is used when parts are being moved into and out of the cleaning chamber. After being cleaned, the parts are moved into the air lock, where the solvent-laden air is then cooled and circulated through a bed of adsorbent until the desired solvent concentration is reached in the air lock. The parts are then removed, and the air lock can be reloaded for the next cleaning cycle. Next, the adsorbent bed is desorbed by circulating heated air from the air lock through the bed and back to the air lock. The new parts are then moved into the cleaning chamber, and the process is repeated.

This technology is similar to that of the completely-enclosed vapor cleaner, except that the air lock can potentially be added to existing vapor cleaning machines. As in conventional vapor degreasing, the condensed solvent in the degreaser would still be collected and distilled to remove contaminants, which results in some solvent being left in the still bottom waste stream. The amount is smaller compared than the amount lost to the air.

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PAINTING

Powder-Coating System

Powder-coating systems apply coating as a powder onto parts without the use of solvents. Dry powder particles from a spray gun are given an electric charge, which creates an attraction to the grounded part. The electric potential holds the powder on the part until it is oven-cured. The main advantage of this process is a transfer efficiency ranging from 95 to 100 percent; therefore, VOC emissions are virtually nonexistent, and no wastewater is discharged. ***Cleanup and recycling of the minimal overspray is easy, because the paint is a solid. This process has a high initial capital cost but a low operating cost, which makes it most beneficial for high-volume production lines.*** However, more surface preparation may be required to achieve a uniform electric potential and a high-quality coating.

Electrodeposition

Electrodeposition methods of painting immerse the part to be coated in an aqueous bath that contains ionized paint materials. A current is run through the part, causing the paint to deposit on the surface. After being withdrawn from the bath, the part is drained and then cured in a conventional oven. ***Capital costs are higher, because equipment is more complex than that required for conventional painting processes. However, because an aqueous solution is used, operating costs are lower.*** With water as the carrier, air emissions are extremely low, thereby eliminating the need for a vapor recovery unit. If the part is sufficiently cleaned, a uniform coating will form even in highly recessed areas of the part. This process is very effective, with transfer efficiencies ranging from 95 to 100 percent.

Radiation-Curable Coating

Changing the curing process also reduces environmental problems, because considerable amounts of VOCs are emitted during the curing process. Conventional drying techniques use either air or heat. Radiation-curable coating, which do not contain or use organic solvents, is an alternative to using solvent-based paints. Reactive monomers are applied as a liquid to a surface, which is then exposed to high-energy radiation, such as UV or infrared light. While the part is exposed to the radiation, reactive cross-linking occurs. ***The advantages of using this coating include the reduction in waste from solvent loss, rapid curing time, a highly durable finish, and a decrease in energy and maintenance requirements.*** Disadvantages include higher coating costs and difficulty in curing irregular-shaped pieces.

Source Reduction through Improved Operating Practices

PAINTING

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Proper Spray Technique

Following are fundamentals of good spray technique:

! Fifty percent overlap of the spray pattern

! Spray gun held 6 to 8 inches from the workpiece

! Constant gun speed of about 250 feet per minute

! Holding the spray gun perpendicular to the workpiece surface

! Triggering the gun at the beginning and end of each pass

If less than a 50 percent overlap is used, the workpiece will become streaked.

If more is used, coating material is wasted, and the operator makes more passes than necessary to finish the piece, requiring excessive time spent on each piece. To maintain a 50 percent overlap, the painter, on the first pass, aims the spray gun nozzle at the edge of the workpiece. On each subsequent pass, the painter aims the spray gun at the bottom edge of the previous pass.

For a uniform finish, the distance between the spray gun and the workpiece must remain constant. A separation of 6 to 8 inches is usually ideal. As the separation increases, the width of the spray pattern on the workpiece increases, and the thickness of the film decreases. Also, a separation of more than 8 inches often results in some of the finishing material drying before it reaches the surface. This dry material either bounces off the surface, thereby wasting material, or sticks to the surface, thereby producing a grainy finish. Spray guns should be adjusted for the separation that will be used, and operators then need to maintain that distance.

A consistent finish also requires a constant gun speed. Changing the speed varies the amount of material being applied to the surface. Low gun speeds may result in the application of too much finish, causing runs. High gun speeds may result in poor aiming, improper gun control, and a distorted spray pattern. All of these demonstrate inefficient use of materials. Gun speeds that are too high may also lead to inadequate coating thickness.

Maintaining the gun perpendicular to the surface is also important. Failing to hold the gun perpendicular to the workpiece results in uneven coating, and the increased angle of incidence of the spray increases the amount of material that rebounds off the surface. Arcing or fanning the gun constantly changes the gun distance and the gun angle, making a uniform finish unlikely.

Training

A company can derive the following benefits from a formal training program for spray operators:

- Reduced material costs
- Higher quality finish
- Reduced VOC emissions
- Less overspray and reduced cleanup costs
- Higher production rate

Training is often conducted on the shop floor by a coworker who shows spray techniques to a new operator. At best, this method of training is inefficient. The trainee will often pick up and repeat the bad habits of the coworker. Also, the coworker will often neglect to convey important points that seem obvious to an experienced operator but are not obvious to a new employee.

Formal training, however, should include an explanation of the fundamentals of good spray technique and how these techniques can benefit the operator. First, good technique makes the job easier for the operator. Through proper spraying, the operator can spray the piece faster and use fewer strokes. For example, if an operator can reduce the number of strokes needed to finish a piece of furniture by just five, and the operator sprays 200 pieces each day, the operator would save 1,000 strokes per day. Second, good spray technique will result in a higher quality finish. Generally, people take pride in their work and will appreciate the opportunity to make a better product.

Ideally, each operator should be videotaped periodically. The operator should then meet with the supervisor and technical personnel to review the tapes. Because spray operators are usually very knowledgeable, they can often identify poor techniques by watching themselves on tape. Constructive advice and "hands-on" instruction under production conditions should follow the videotape review. Next, the operators should be retaped and given an opportunity to compare the two tapes. This allows the operators to see their improvement. ***One company, conducting this training twice a year, reported an 8 to 10 percent reduction in the amount of finishing material being used, resulting in an annual savings of $50,000 to $70,000.***

Even with good training, supervision is necessary to ensure that operators do not revert to bad habits. To maximize transfer efficiency, regardless of the type of system used, excessive air or fluid pressure must be avoided to maximize transfer efficiency. Also, training must be specific to the equipment and materials being used. For instance, because of their higher solids content, waterborne coatings do not need to be applied as thickly as do solvent-based finishes.

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On-Site Reuse and Recycling

The best option, whenever possible, is to recycle materials on-site and return them to the process. Wastes should be recycled within a process. ***On-site recycling can (1) reduce disposal costs, (2) decrease material costs, and (3) decrease liability associated with disposal.*** One example is when overspray is captured in the water flowing over a series of baffles at the back of a wet spray booth and the paint is reused. If the paint is immiscible with water, the material can be easily separated from the water, and it may be possible to return the paint to the process. Another example is the on-site solvent reclamation described in Chapter 2.

When on-site recycling is not possible, a company can obtain many of the same benefits from off-site recycling and may even receive some income from selling waste. Chapter 1 provides some tips on setting up a recycling program.

MACHINING OPERATIONS

Recycling deteriorated or contaminated metalworking fluids can reduce costly hauling and disposal. Recycling also minimizes the need to purchase additional fluid concentrates. The focus of on-site recycling is to extend the useful life of the metalworking fluids, rather than to separate and refine the oil it contains, as is the case with off-site recyclers. Continuous on-site filtration of fluids reduces the requirements for new fluids, avoids recycler's charges, and saves money by reducing machine downtime for cleaning and coolant recharge. Methodologies for recycling metalworking fluids include filtration, ultrafiltration for water removal, skimming, flotation, coalescing, hydrocycloning, centrifuging, pasteurization, and downgrading.

PAINTING

Paint application equipment—spray guns, hoses, brushes, and rollers—is often cleaned with solvents. Cleaning wastes can sometimes be recycled in the following ways:

- Collect and reuse the solvent-paint mixture in the next compatible batch of paint as part of the formulation.
- Distill the mixture to reuse the solvent and, possibly, the paint.
- Separate out the paint sludge—through filtration, centrifugation, or decantation—and reuse the solvent.
- Collect the cleaning wastes, and reuse for cleaning—perhaps in another application—until the solvent is too contaminated for further use.

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MERCURY

Although the amount of mercury in electrical lighting is small, ***there is a growing market for recycling mercury, glass, and aluminum from fluorescent and mercury vapor lamps.*** The recovery process typically involves crushing the tube and separating the metal end pieces from the glass. Metal components, such as the end caps, are often sent to other recyclers for recovery. The tube components are then roasted and retorted to recover mercury. The glass, phosphor, and mercury may be treated together, or the glass may be separated and only the phosphor treated. The resulting glass is often recycled. Mercury recovered by retorting is purified by distillation for reuse.

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Section III

Case Studies

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CASE STUDY NO. 1—Printed Circuit Board Manufacturer

Introduction

This plant, which requested it remain unidentified, is a mid-size facility that operates two 8-hour shifts per day for 50 weeks per year. It manufactures about 1,000 square feet of single-layer and multilayer printed circuit boards each day.

Processes Prior to Pollution Prevention

The company was using proven manufacturing techniques; however, these techniques resulted in the production of large volumes of waste solvents and metals-bearing wastewater.

Current Processes

The facility was very aggressive in its source reduction efforts, targeting the board preparation, photoimaging, and metals plating processes.

In the initial board preparation process, solvent drying was replaced with water, significantly reducing the solvent waste.

In the photoimaging operation, silkscreening that is used to transfer the circuit was replaced with a dry film process, which eliminated chlorinated solvents from the operation.

Several waste minimization practices were implemented in the plating operations. For the electrolytic copper plating process, the facility switched from a flowing water rinse to a still dragout tank, with increased drain times, to reduce copper discharge to the wastewater treatment system. In the electrolytic copper process, the company replaced the first flowing rinse with a spray rinse. Water supply to the electroless copper plating, electrolytic copper plating, and gold tab plating lines was divided so that each line had a separate supply valve. The water supply to all of these lines was formerly controlled by one valve, which resulted in wasted water when a particular line was not in use. The facility replaced the tin/lead solder with unalloyed tin, thereby reducing lead contamination in wastewater.

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Savings

Depending on the waste minimization technique, ***the company reduced its annual waste production by 25 to 88 percent.*** The reduction in waste metals sludge, waste solvents, and water consumption ***saved the company an estimated $160,000 in annual waste disposal costs and water consumption costs.*** The company also realized reduced labor costs for operating and maintaining its wastewater treatment system, and less time required to manage its hazardous wastes.

Taken from "Waste Minimization Assessment for a Manufacturer Producing Printed Circuit Boards," U.S. Environmental Protection Agency.

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CASE STUDY NO. 2—Copper Recovery

Introduction

Diversified Technologies, Inc. (DTI), a small facility located in Jamestown, North Carolina, manufactures printed circuit boards for the electronics industry.

Process Prior to Pollution Prevention

The company used a series of etching, metal plating, acid cleaning, and rinse baths. The spent baths and static rinses are chemically treated to remove heavy metals before discharge to the sanitary sewer, resulting in a significant volume of sludge, which is disposed of offsite. Each ton of the sludge contained about 320 pounds (16 percent) of copper.

Current Process

DTI evaluated several methods for electroplating copper out of the wastewater before chemical treatment. Problems encountered included slow plating rates caused by reductions in electronegative potential, inhibition of electrical current flow, and short anode life. Because each bath contained different constituents that affected copper removal efficiency, DTI evaluated several cathodes and anodes.

DTI found that, to plate out copper, it needed an area cathode with a high surface area. DTI used scrap polypropylene mesh to electroless plate out 0.001 inch of copper. This plated mesh was not affected by strong acid solutions, and was subsequently used as the cathode to plate out down to 0.5 parts per million (ppm) of copper from all baths. Lead, platinized titanium, and carbon anodes were found to be successful for various process baths and static rinses.

Copper was recovered from etch baths and etch static rinses by using lead, platinized titanium, or carbon anodes because of the sulfuric acid content. A platinized titanium or lead anode was used to recover copper from the accelerator baths, electroless copper baths, static rinses, sulfuric acid dips, and acid copper plating rinses. A carbon anode was used to recover copper from the fluoboric acid dips.

Savings

Before implementing this project, DTI was producing 1 pound of hazardous waste sludge for every 232 gallons of wastewater treated. After DTI implemented the copper plating-out project, it was producing 1 pound of hazardous waste sludge for every 1,156 gallons of wastewater treated, ***an 80 percent reduction in sludge.*** The use of wastewater treatment chemicals also declined, resulting in an additional savings. ***The annual savings to DTI were $5,958.***

Taken from "Pollution Prevention Case Studies," North Carolina Department of Environment, Health, and Natural Resources.

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CASE STUDY NO. 3—Water Use Reduction

Introduction

Mitsubishi Semiconductor America, Inc. (MSAI), is a large facility located in Research Triangle Park, North Carolina. MSAI manufactures semiconductors for various applications.

Process Prior to Pollution Prevention

MSAI used large volumes of water to manufacture integrated circuits, resulting in large volumes of wastewater. MSAI targeted a manufacturing process that required large volumes of water for various pollution prevention techniques.

Current Process

MSAI developed three projects for reducing water consumption and, consequently, wastewater production. In the first project, MSAI installed timers and resistivity meters at wet benches. The timers automatically turn off the flow of water at the benches, and the meters divert process wastewater that is recyclable. Wastewater that meets purity specifications is recycled through the process until the resistivity decreases to a specified level, after which it is discharged to the facility's wastewater treatment system.

In the second project, MSAI recycled, instead of discharging, the rinse water from the deionized water column regeneration process back to the columns until the rinse water reached a specific resistivity.

In the third project, MSAI added processes to the two wastewater treatment systems to reuse wastewater. First, neutralized acid and alkali wastewater was deionized and used as a high purity water make-up. Second, neutralized fluoride rinse waters were used to wash chemical process containers for recycling.

Savings

MSAI reduced its monthly water consumption from 11.7 to 4.2 million gallons, a reduction of 64 percent. The quantity of sludge from the wastewater treatment system decreased by almost 50 percent. Cost savings were also significant. ***The annual cost of water decreased from $1.4 million to $492,000. The annual cost savings with MSAI's pollution prevention program is about $747,000.***

Taken from "Pollution Prevention Case Studies," North Carolina Department of Environment, Health, and Natural Resources.

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CASE STUDY NO. 4—Recovery of Metals

Introduction

Circuit Partners, Inc. (CPI) is a mid-size printed circuit board manufacturer located in Issaquah, Washington. CPI produces single-sided, double-sided, and multilayer printed circuit boards for military, consumer, and aerospace electronics application.

Processes Prior to Pollution Prevention

The etch, electroless plating, and electrolytic plating lines used once-through rinse waters to clean the processed boards. This engineering resulted in the production of a large amount of relatively dilute metals-bearing wastewater.

Current Process

The first step that CPI took to recover metals was to change the engineering of the rinsing systems, which enabled CPI to use a smaller, more efficient metals recovery system. First, CPI installed countercurrent rinsing in the electroless and electrolytic plating processes. Second, CPI replumbed the rinsing baths so that the effluent from cleaner baths was used as make-up water for rinse stages that were more contaminated. Third, CPI installed timers on the rinse tanks to increase efficiency. These baths have since been upgraded with conductivity bridges to monitor bath cleanliness and maximize use of plating solutions.

After reducing the water consumption of the rinse systems, CPI installed electrolytic plate-out units to recover copper from spent plating solutions and first-stage rinse tanks. The recovered copper is sold to recyclers. The recovery system also helps to increase the life of the rinse baths.

Waste streams containing other metals, such as lead and nickel, are segregated and treated with sodium borohydride, a precipitating agent. This process generates a smaller volume of solids than traditional hydroxide precipitation, resulting in less sludge and lower costs for shipping, handling, and treatment.

Savings

CPI saves money by selling the recovered copper to recyclers, by reducing the amount of chemicals used to treat the metals-bearing wastewater, through reduced waste disposal costs, and by reducing the amount of water consumed. ***CPI estimates that it saves over $23,000 a year by recovering metals.***

Taken from "Success through Waste Reduction, Proven Techniques from Washington Business, Volume II," Washington State Department of Ecology.

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CASE STUDY NO. 5—Reduction in Chemical Usage

Introduction

Siltec Corporation (SC) Circuit Partners, Inc., is a mid-size silicon wafer manufacturer in Menlo Park, California. SC, which manufactures polished and epitaxial silicon wafers, employs about 600 employees.

Processes Prior to Pollution Prevention

The SC pollution prevention program targeted each manufacturing operation for ways to (1) reduce or eliminate toxic substances in the workplace, (2) minimize or eliminate generation of hazardous waste, and (3) conserve resources. SC targeted chemicals used in cleaning, etching, polishing, and drying processes.

Current Process

SC's approach was to simplify operations and identify processes in which it could reduce chemical usage while maintaining product quality and production efficiency. SC revised several processes to eliminate chlorofluorocarbons (CFC), replacing them with water-cleaning processes. Trichloroethane and trichloroethene were eliminated from cleaning and wafer polishing operations, respectively, because of the risk to employee health. Several alternative chemicals were evaluated. SC replaced trichloroethane with a heated mixture of commercial wax stripper and caustic, and replaced trichloroethylene with a commercial wax stripper. Acetone was replaced with isopropyl alcohol (IPA) as a cleaning and drying agent. Waste IPA is now burned onsite in two boilers. Use of ammonium hydroxide and hydrogen peroxide was reduced by one-third by reducing the number of process units from six to four.

Savings

Between 1989 and 1990, SC reduced the use of chemical cleaners, etchants, polishers, and drying agents by one-third. ***This resulted in a cost savings of more than $445,000.***

Taken from "Electronics Industry Casebook," Pacific Northwest Pollution Prevention Research Center.

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CASE STUDY NO. 6—Printed Circuit Board Manufacturer

Introduction

Pacific Circuits, Inc. (PCI), located in Redmond, Washington, manufactures double-sided and multilayer circuit boards for medical and telecommunications industries. It employs about 300 people and produces about 1,400 circuit boards each day.

Process Prior to Pollution Prevention

PCI replaced several process chemicals with substitutes that are less hazardous, reduced the use of some metals, and eliminated the use of some chemicals. PCI also automated much of the plating operation and reduced water consumption.

Current Processes

PCI replaced all butyl carbitol/potassium hydroxide dry film strip with a nonhazardous substitute, replaced 90 percent of the solvent-based epoxy solder masks with dry film masks, and replaced 1-ounce copper foil with 0.5-ounce copper foil. These changes reduced the hazardous wastes being generated and shipped offsite.

PCI reduced the use of tin/lead plating as an etch resist, resulting in the reduction of more than 6,000 pounds of lead waste in 1991 and 1992. PCI also eliminated the use of sulfuric acid in desmear applications by substituting a nontoxic substance. This resulted in a reduction in the potential hazard of chemicals in the workplace.

PCI reduced the metals-bearing rinse waters being generated by making several changes, including reducing dragout with air knives and squeegee rollers, and reducing the concentration of metals in micro-etchants.

The installation of two new automated plating lines, which mechanize the transport of circuit boards from bath to bath, resulted in improved control of water and chemical usage, as well as improved product quality. The replacement of metal overhead racks—to which metals were plated during circuit board production—with plastic coated racks resulted in the virtual elimination of the use of nitric acid, which was used to strip the metal from the racks.

Electrolytic cells were installed in-line with the micro-etch baths to recover metallic copper. This process recovers more than 5,200 pounds of metallic copper each year.

Water consumption was reduced by installing spray rinses, flow restrictors, countercurrent washing, and automated plating lines.

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Savings

Installation of the automated plating lines resulted in ***a reduction of 50,000 pounds of nitric acid waste***. Installation of the copper recovery units resulted in ***a 40 percent reduction (about 50,000 pounds) of wastewater treatment sludge.*** Indirect savings resulted from the reduction in the use of wastewater treatment chemicals. No information was available concerning the cost savings.

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Taken from "Electronics Industry Casebook," Pacific Northwest Pollution Prevention Research Center.

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CASE STUDY NO. 7—Semiconductor Manufacturer

Introduction

Intel is located in Aloha, Oregon. It manufactures semiconductors for computer systems and employs about 5,400 people.

Processes Prior to Pollution Prevention

Intel identified several manufacturing processes as candidates for its pollution prevention program. These processes involved solvent cleaning and acid etching that use four different chemicals—Freon (CFC-113), acetone, sulfuric acid, and phosphoric acid.

Current Processes

Intel redesigned an assembly process that used a Freon 113 cleaner. Intel switched to water-soluble pastes and fluxes, eliminated the chemical cleaning steps, and used water to clean. The use of 75,000 pounds of Freon was eliminated. Intel reduced the amount of acetone (by 30 percent) used to clean photoresist application equipment by installing controls with which the process was optimized. Installation of a filtration process reduced sulfuric acid consumption by 43 percent and improved acid purity. Intel identified a fertilizer manufacturer that now purchases about 100,000 pounds of waste phosphoric acid from an aluminum etch process, which was formerly treated and discharged to a nearby river.

Savings

Intel's pollution prevention program focused on replacing chemical cleaners, reducing chemical usage, improving chemical life, and finding a market for wastes. Chemical usage was reduced by 264,000 pounds per year, and waste generated was reduced by more than 1 million pounds per year. ***The cost savings of the program amounts to more than $350,000 per year.***

Taken from "Electronics Industry Casebook," Pacific Northwest Pollution Prevention Research Center.

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CASE STUDY NO. 8—Process Redesign and Recycling

Introduction

Hewlett-Packard (HP) operates an electronics facility in Corvallis, Oregon, that manufactures integrated circuits and finished consumer products. The plant has about 3,000 employees.

Process Prior to Pollution Prevention

HP used CFC cleaners and chlorinated solvents, such as trichloroethene and trichloroethane. Nickel plating wastewater was treated onsite, resulting in a metals-bearing sludge that was disposed of offsite. Production lines relied on obsolete engineering practices.

Current Process

HP phased out the use of CFCs and chlorinated solvents over 5 years. These chemicals were replaced with citrus-based solvents and water-based cleaners.

HP recycles nickel plating waste, which has eliminated 12,000 pounds per year of heavy metal sludge.

New, more efficient chemical dispensing pumps were installed, which has resulted in reduced chemical usage. HP also changed aspects of its production to extend the life of chemical baths and reduce the frequency of chemical bath dumping.

Savings

HP has saved money by reducing disposal costs for the heavy metal sludge and by reducing the costs of chemicals for treating the nickel wastewater. HP has also reduced the costs to purchase process chemicals, because they now are used more efficiently and for longer periods of time. ***These process changes, chemical substitution, and recycling efforts provide an annual cost savings of more than $450,000.***

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Taken from "Electronics Industry Casebook," Pacific Northwest Pollution Prevention Research Center.

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CASE STUDY NO. 9—Chemical Substitution, Process Redesign, and Resource Conservation

Introduction

A small facility in the U.S., which employs less than 500 people, manufactures silicon-based integrated circuits (rectifiers) for converting alternating current into direct current. The plant operates one 8-hour shift and produces about 2.5 million units yearly.

Processes Prior to Pollution Prevention

The facility uses volatile chlorinated solvents as strippers and degreasers, various acids and bases, and reverse osmosis to prepare ultrapure water for cleaning. The facility scrubs solvent air emissions with water.

Current Process

The facility reuses the reverse osmosis reject water to scrub solvents from air emissions. This has resulted in a reduction of 800,000 gallons of wastewater effluent.

The facility replaced the solvent-based photoresist stripper with a water-soluble, biodegradable stripper. This has reduced employee exposure to a potentially toxic substance and has reduced the flammable and toxic hazardous waste.

The facility replaced 1,1,1-trichloroethane vapor degreasing with a nontoxic, nonhazardous, low volatility aqueous cleaner and cleaner rinse. This has also reduced employee exposure to a potentially toxic substance and has reduced the flammable and toxic hazardous waste being generated.

Savings

Cost savings were realized through a reduction in the hazardous waste being generated and the associated disposal costs. ***The annual cost savings are about $4,000.***

Taken from "Waste Minimization Assessment for a Manufacturer of Silicon-Controlled Rectifiers and Schottley Rectifiers," U.S. Environmental Protection Agency.

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CASE STUDY No. 10—Maquiladora Success Story

Introduction

The EDUMEX plant is one of the larger maquiladora facilities in Ciudad Juarez, Mexico, employing over 1,000 people. The facility has manufactured electronic and electric products, diskette components, abrasive belts, ceramics, and other products since 1985. EDUMEX is a registered hazardous waste generator in Mexico, although minimal hazardous wastes are generated. The primary waste streams are abrasive materials, plastics, trash, and cardboard packing materials.

Pollution Prevention at EDUMEX

The employees at EDUMEX have developed their processes to minimize waste. Pollution prevention and recycling are broadly used. Examples include the following:

- Products and processes are selected that minimize the use of hazardous materials and reduce the hazardous wastes that are generated.
- Strict inventory controls ensure product quality and minimize wasted material.
- "Cut-offs" from abrasive and adhesive production facilities are recycled as feedstocks for the Juarez facility.
- Cardboard is recycled.
- Management's policies are designed to minimize employee turnover while maximizing employee training.

Recognition

In December 1993, the plant received the Secretaria de Desarrollo Social's SEDESOL (SEMARNAP's precursor) Green Flag award for environmental compliance. The facility was also featured in a joint project—aimed at strengthening pollution prevention along the Mexico/Texas border—between SEDESOL and the Texas Natural Resource Conservation Commission (TNRCC).

Taken from "Voluntary Pollution Prevention Site Assistance for Four Maquiladoras of the Texas/Mexico Border Region," TNRCC.

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CASE STUDY NO. 11—Manufacturer of DC Electric Motors

Introduction

A team from the University of Tennessee assessed waste minimization opportunities at a plant that manufactures permanent-magnet direct current (DC) electric motors and repair parts.

Process Prior to Pollution Prevention

At the plant, armatures and stators are manufactured separately and assembled into complete motors. The plant produces about 13 million motors and parts annually. Major processes at the plant include machining, epoxy coating, varnish coating, surface preparation, gluing, curing, tolerancing, assembly, cleaning, painting, and packaging. Other than scrap metal and waste coolant, the two largest waste streams are paint wastes and waste epoxy powder. Parts are manually painted by using compressed air spray guns. Overspray is captured in a water curtain and disposed of as a hazardous waste. Epoxy is applied, after preheating, by dipping each part in a powder dip tank and allowing it to cool. The excess epoxy powder absorbs moisture from the atmosphere and must also be disposed of as a hazardous waste.

Pollution Prevention Opportunities

Although only about 2 percent of the plant's products are painted, the painting operations provided opportunities for significant cost savings and pollution reduction. One option was to replace the compressed air paint spray guns with air-assisted airless spray guns. The decreased overspray would reduce paint solids and liquids wastes by 50 percent each. Another option for the facility was to use an inactive electrostatic spray paint booth to replace the water curtain spray booth that was being used. This would require retraining personnel but would reduce material costs and reduce the waste being generated, cutting paint waste nearly in half.

Installing an airtight collection system to recycle spent epoxy powder would reduce waste epoxy powder by 90 percent.

Savings

Replacing the spray guns would save about $5,850 annually, and the savings would pay for the conversion within 2.6 years. Using the inactive electrostatic spray booth would save nearly $10,000 annually, with a payback period of less than 9 months.

Installing the epoxy powder recycling system would save the facility almost $15,000 annually. Savings would pay for the systems installation within 6 months.

Taken from "Environmental Research Brief: Waste Minimization Assessment for a Manufacturer of Permanent-Magnet DC Electric Motors," U.S. Environmental Protection Agency.

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CASE STUDY NO. 12—Electronics Manufacturer

Introduction

Norand Corporation, located in Cedar Rapids, Iowa, manufactures sophisticated hand-held computer systems, and radio and TV equipment. Virtually all components—as well as the final products—are manufactured on site through machining, fabrication, plating, soldering, assembly, and finishing operations.

Process Prior to Pollution Prevention

The company had already worked to reduce the amount of Freon used to clean its PC boards but was still emitting about 1,000 gallons of Freon to the atmosphere annually.

To prepare aluminum surfaces for painting, four 60-gallon containers were used; one contained sulfuric acid, one contained chromic acid, and two contained water. The waste chromic acid required disposal as a hazardous waste.

Current Process

Norand installed alternative soldering equipment that uses low-solids flux that does not require Freon cleaning, thereby eliminating the use of Freon at the facility. The company also invested in 70 new hand soldering guns.

The company replaced the chromic acid with phosphoric acid, which eliminated the generation of chromic acid waste that was being generated. The phosphoric acid is safely neutralized on site and discharged to a municipal sewer.

Savings

Using the new soldering equipment saved the company $65,000 per year in waste disposal, operating, and supply costs, and Norand reported superior quality soldering from the new equipment. The payback time for this project was documented to be 2.9 years.

Eliminating the use of chromic acid saved the company $3,100 annually in waste disposal costs. The savings paid for implementing the new system in less than 6 months.

Other changes that reduced waste and saved money for Norand include the following:

- Solvent wastes that were previously incinerated with no energy recovery were redirected to a company that used them as an alternative fuel, saving $1,360 annually.

- Norand sold 2,000 pounds per year of aluminum scrap—which would have otherwise been landfilled—to a scrap metal dealer.

- Forty incandescent lights were replaced with compact fluorescent bulbs that screwed directly into the incandescent fixtures, resulting in a savings in annual electricity of almost $3,000.

- Toner cartridges—previously thrown away—are returned to the supplier.

- Norand established a recycling program for cardboard, white paper, and other paper, which cost virtually nothing and saved almost $4,000 per year in lower waste disposal costs and increased revenue, in addition to diverting 75 tons per year from landfills.

- Norand employees had consumed about 468,000 styrofoam cups per year. The company spent $2,821 to buy every employee a ceramic cup with the company logo on it to use instead of the styrofoam cups. This saved $7,428 per year.

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Taken from "Pollution Prevention Works for Iowa, Case Studies," Iowa Department of Natural Resources.

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CASE STUDY NO. 13—Ultrasonic Cleaning

Introduction

The Conax Buffalo Corporation (Conax) manufactures precision products for industrial, aerospace, nuclear, fiber optic and military applications.

Process Prior to Pollution Prevention

Metals parts—contaminated with oils, coolants, dirt, and metal shavings—were cleaned by using two types of Freon-based solvents in two vapor degreasers and two benchtop stations. These cleaning operations generated more than 10,000 pounds of fugitive emissions per year.

Current Process

The Freon-based cleaning systems have been replaced by a series of modular cleaning and rinsing tanks. Parts are placed in a tank containing an aqueous cleaning solution. Ultrasonic transducers are mounted on the side of the tank to accelerate the cleaning. The tank is also equipped with a sparger system and overflow weir to remove insoluble oils and extend bath life. After the ultrasonic tank, the parts are rinsed in two successive water tanks (this minimizes water use). A hot rinse, which speeds part drying, is the final cleaning step. Parts that tend to retain water are further dried with an air gun.

Savings

By installing the ultrasonic cleaning system and eliminating the two benchtop stations and one vapor degreaser, Conax reduced volatile emissions by about 86 percent. Twenty-six drums of still bottoms, previously generated through solvent reclamation, were also eliminated. ***The company projects annual savings of $27,178 from lower operating and waste disposal costs.***

Taken from "Project Summary: Ultrasonic Cleaning as a Replacement for a Chlorofluorocarbon-Based System," U.S. Environmental Protection Agency.

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CASE STUDY NO. 14—Weapons Systems Manufacturer

Introduction

General Dynamics Pomona Division (GDPD) manufactures various tactical weapon systems for the military. Operations at the plant include printed circuit board production, painting, paint stripping, and part cleaning.

Pollution Prevention Initiatives and Results

GDPD installed a computerized printed circuit board plating system. The system uses a spray rinse dip rinse, which helped to reduce the system's water usage by 80 percent. The system also uses a copper-recovery system—using short-bed ion exchange columns and electrowinning techniques—to eliminate a major waste stream and produce salable scrap copper. Though it is expensive, the system produced significant savings in labor and waste treatment costs over those of the original system. The payback period for the new system was estimated to be 8.3 years.

GDPD installed a plastic bead-blast paint stripper to replace the previous stripping system, which used methylene chloride as a stripping agent. Using the reusable plastic beads is a mechanical stripping process that is similar to sandblasting. Less waste is produced, resulting in a $5,000 per year savings in waste disposal and a payback period of about 3.6 years.

Through these and other pollution prevention initiatives, the GDPD plant reduced its volatile organic compound emissions by about 95 percent, and its discharge of hazardous liquid and solid wastes by 97 percent.

Taken from "Project Summary: Evaluation of Five Waste Minimization Technologies at the General Dynamics Pomona Division Plant," U.S. Environmental Protection Agency.

APPENDIX

ADDITIONAL INFORMATION

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APPENDIX
ADDITIONAL INFORMATION

The following are additional documents on pollution prevention that you may find useful. Unfortunately, they are available only in English. Copies of documents with an U.S. Environmental Protection Agency (EPA) document number may be obtained from the EPA Center for Environmental Research Information (CERI) or the Pollution Prevention Information Clearinghouse (PPIC). Some documents are available, without charge, from PPIC. For a current list of these documents, please contact PPIC.

EPA CERI Publications Unit
26 West Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7562

PPIC
401 M Street
Mail Code PM221A
Washington, DC 20460
(202) 260-1023

PIES
Technical Support Office
SAIC
7600-A Leesburg Pike
Falls Church, VA 22043
(703) 821-4800

GENERAL INFORMATION

American Institute for Pollution Prevention. 1993. "A Primer for Financial Analysis of Pollution Prevention Projects." EPA/600/R-93/059. April.

Higgins, Thomas. 1989. *Hazardous Waste Minimization Handbook*. Lewis Publications, Inc. Chelsen, Michigan.

California EPA, Department of Toxic Substances, Source Reduction Research Partnership. 1991. Electronics Products Manufacture. June.

Toxics Use Reduction Institute. (no date). "Massachusetts Toxics Use Reduction Program, Curriculum for Toxics Use Reduction Planners." University of Massachusetts. Lowell, Massachusetts.

United Nations Environment Programme, Industry and Environment. 1993. "Cleaner Production Worldwide." March.

U.S. Environmental Protection Agency (EPA). 1989. "Pollution Prevention Benefits Manual, Volumes I and II, Phase II." Office of Policy Planning and Evaluation and Office of Solid Waste. October.

U.S. EPA. 1992. "Facility Pollution Prevention Guide." Risk Reduction Engineering Laboratory, Office of Research and Development. Ohio. May.

U.S. EPA. 1992. "Industrial Pollution Prevention: A Critical Review." *Journal of the Air and Waste Management Association*. Vol. 42, No. 5. May. Pages 617-655.

U.S. EPA. 1993. "Watts Nickel and Rinse Water Recovery via an Advanced Reverse Osmosis System." EPA/600/SR-93/150. October.

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U.S. EPA. 1993. "Carbon-Black Dispersion Preplating Technology for Printed Wire Board Manufacturing." EPA/600/SR-93/201. December.

U.S. EPA. 1994. "Abstracts of Pollution Prevention Case Study Sources." EPA/742/B-94/001. January.

U.S. EPA. 1994. "Waste Minimization Assessment for a Manufacturer of Electrical Rotating Devices." EPA/600/S-94/018. September.

University of Michigan National Pollution Prevention Center. 1993. "Agent Regeneration and Hazardous Waste Minimization, IBM Corporation." Document No. 93-1. April.

SOLVENT SUBSTITUTION AND RECYCLING

Toxics Use Reduction Institute. 1993. "Health and Safety Impacts of Citrus-Based Terpenes in Printed Circuit Board Cleaning." Technical Report No. 6. University of Massachusetts. June.

Ohio EPA. 1993. "On-Site Solvent Recycling Equipment." Fact Sheet No. 9. January.

Pettengill, Nancy, Alan Moyal, and Kenneth Toliver. 1992. "Implementing Solvent Reprocessing at IBM East Fishkill through a Design/Construct Partnership." Proceedings—Institute of Environmental Science. Pages 497-511.

ALTERNATIVE COATING AND APPLICATION METHODS

Bankert, Peter J. 1990. "Waterborne Paint Circulation." *Industrial Finishing.* July. Pages 42-43.

Industrial Finishing. 1990. "How Rapid Rack Raised Transfer Efficiency." October. Pages 20-24.

North Carolina Department of Environment, Health, and Natural Resources. (no date). "Overview of Coating Technologies." Sharon M. Johnson.

Marg, Ken. 1989. "HVLP Spray Puts You into Compliance." *Metal Finishing.* March. Pages 21-23.

Robinson, Frank, and Dennis Stephens. 1990. "Understanding Electrostatic Finishing." *Industrial Finishing.* September. Pages 34-37.

Schrantz, Joe. 1989. "New CO_2 Spray Finishing Technology!" *Industrial Finishing.* September. Pages 27-32.

Schrantz, Joe. 1990. "Exciting Infrared and UV Developments." *Industrial Finishing.* September. Pages 14-21.

Walberg, Arvid C. 1990. "Boost Overall Transfer Efficiency." *Industrial Finishing.* May. Pages 20-30.

METALWORKING FLUIDS

Ohio EPA. 1993. "Extending the Life of Metal Working Fluids." Fact Sheet No. 11. March.

U.S. EPA. 1993. "Mobile Onsite Recycling of Metalworking Fluids." EPA/600/SR-93/114. August.

U.S. EPA. 1993. "A Fluid Recycling Device for Industrial Fluid Users." EPA/600/SR-93/154. September.

SURFACE TREATMENT AND CLEANING

U.S. EPA. 1993. "Evaluation of Ultrafiltration to Recover Aqueous Iron Phosphating/Degreasing Bath." EPA/600/SR-93/144. September.

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RECYCLING

Blackman, Ted. 1991. "Recycling: Not Just for Papers and Bottles Anymore." October. Pages 19-20.

ALTERNATIVE BOARD TESTING

U.S. EPA. 1994. "Electronic Cooling Alternatives: Compressed Air and Liquid Nitrogen." EPA/600/SR94/170. September.

COMPUTER SOFTWARE

U.S. EPA. 1992. "User's Guide: Strategic Waste Minimization Initiative (SWAMI) Version 2.0, A Software Tool to Aid in Process Analysis for Pollution Prevention." January. EPA/625/11-91/004.

U.S. EPA. 1991. "SWAMI Version 2.0." May.

ATTACHMENT A

INFORMATION ON ACCESSING POLLUTION PREVENTION INFORMATION CLEARINGHOUSES

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ATTACHMENT A
INFORMATION ON ACCESSING POLLUTION PREVENTION INFORMATION CLEARINGHOUSES

Envirosense Database
U.S. EPA
Bulletin Board: (703) 908-2092
Help Line: (703) 908-2007

Electronics Manufacturing Productivity Facility (EMPF)
714 North Senate Avenue
Indianapolis, IN 46202-3112
(317) 226-5607
FAX: (317) 226-5615

Pollution Prevention Information Clearinghouse (PPIC)
U.S. EPA
401 M. Street, SW (3404)
Washington, DC 20460
(202) 260-1023

Manufacturing Extension Partnership (MEP)
U.S. Department of Commerce
National Institute of Standards and Technology (NIST)
(301) 975-5020

National Roundtable of State Pollution Prevention Programs
(202) 543-P2P2 (7272)

Ozonet Database
Institute for Interconnecting and Packaging Electronic Circuits (IPC)
Lincolnwood, IL
(708) 677-2850

EPRI
Center for Materials Fabrication
505 King Avenue
Columbus, OH 43201

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Directions for How to Connect and Register
on the Enviroene BBS via Modem

This document (which can be viewed in the BULLETINS section of Enviroene' BBS or downloaded from the UTILITIES directory of the Enviroene (E$) Communications Network. It does not provide any details concerning the World Wide Web (WWW) platform of Enviroene.

Enviroene (703/908-2092) TELEPHONE/ADDRESS INFORMATION:

HOTLINES:
BBS: 703/908-2007
WWW: 703/526-6956

CO-MANAGERS:
BBS Platform: Louis Paley, 202/260-4640
WWW Platform: Myles Morse, 202/260-3161

WWW/INTERNET ADDRESS
http://wastenot.inel.gov/envirosense/

I. THE ENVIROENE NETWORK:

The Enviroene Communications Network is a free, public, interagency-supported system operated by EPA's Office of Enforcement and Compliance Assurance and the Office of Research and Development. The Network allows regulators, the regulated community, technologists, and the general public to share information regarding: pollution prevention and innovative technology; environmental enforcement and compliance assistance; laws, executive orders, regulations, and policies; points of contact for services and equipment; case studies; technical databases; and other related topics. The Network welcomes receipt of environmental messages, information and data from any public or private person or organization.

II. SUMMARY INSTRUCTIONS—CONNECTING AND REGISTERING:

! Connect to E$ via a modem, using communications software set to conventional BBS settings, by calling:

(703) 908-2092

! Hit the RETURN/ENTER ("RETURN" is used hereafter to represent this key regardless of what your keyboard name is or where it is located) key twice (2) if you want to get the default values for the screen;

! On successive screens, type your first name and hit RETURN; type your last name and hit RETURN; and type your password (if you have NOT registered yet, make one up and make a note of it) and hit RETURN; and

! Register (first time only) and immediately receive access to the BBS for 120 minutes per day;

- Type responses to the Registration questions. and hit RETURN to begin using Enviroene.

NOTE: When working within Enviroene, one may generally abort scrolling by typing "N"; and one may generally return to a menu screen by hitting RETURN, either once or twice as needed in a particular situation.

III. DETAILED INSTRUCTIONS—CONNECTING AND REGISTERING:

A. Modem Settings

Connecting to the Enviroene BBS is done using a modem and communications software. The modem can be either an internal or external model connected directly to your PC. The communications software (e.g., CrossTalk[1], ProComm, QModem, etc.) is what allows you to access and control your modem. Your software needs to be set to the values noted below:

! **Telephone Number -** 703-908-2092

! **Baud Rate -** up to 14,400 BPS is supported (always select the highest speed which YOUR modem will support);

! **Terminal Emulation -** BBS, ANSI, VT-100, VT-102 (TTY for MacIntoshes), etc.;

! **Data Bits -** 8 (Eight);

! **Stop Bits -** 1 (One);

! **Parity -** None;

! **Transfer Protocols -** ZModem, YModem, XModem, HS/Lin, BiModem, ASCII (text files only). Zmodem is very efficient. You must select the same protocol that BOTH your communications software and the BBS support so that they can "talk the same language;" and

! **Error Correction/Data Compression Protocols -** v.32, v.42 - and other older, hardware-dependent protocols are supported.

Refer to your communications software manual on how to set and save the communication parameters noted above (these will generally be the default).

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B. Registration Procedure (first time only)

After you tell your software to dial in, a connection should be established and you should see the opening screen for the Enviroene BBS.

- ! Accept the default settings by hitting "RETURN" twice;
- ! Type in your first name, hit RETURN; type in last name, and hit RETURN;
- ! ES checks to see if you are already registered; if you are not registered, type "C" to register and hit RETURN;
- ! Respond to each of the questions regarding name and address information and hit RETURN repeatedly until you are sent to the "List of Bulletins";
- ! Read the bulletins, and exit to E$' "System Menu";
- ! Set the desired "file transfer protocol" (matching it to whatever you set on your PC) by typing "S(et) File Transfer Protocol" at the System Menu and hit RETURN;
- ! Type "V(iew) Current Settings" to confirm your answers and settings and hit RETURN;
- ! Type "C(hange) Settings" if any need to be changed; and
- ! Type "Q" to exit back to the System Menu.

C. Initial E$ Use

- ! ENJOY USING Envirosense by taking the following steps:
  - Conduct file (document) searches ("S");
  - Look at directories and file ("F");
  - Look at new files ("N");
  - Upload files ("U");
  - Download files ("D");
  - Read or leave messages ("M")
  - Read bulletins ("B"); or
  - Go through the door ("O") to access one of several databases.

Additional help is available on-line by typing "H" at almost any BBS area (e.g., type "S", then "H" in response to the "Text to Scan For" question). Also read the help bulletins (in BULLETINS) or download the files from the Utilities directory (#160). These bulletins explain how to connect and register, find and view, convert to text, compress, and uncompress, download .TXT and .ZIP[2] files, and upload files. The titles of the files are: "CONREGWP.TXT," "FINDVIEW.TXT," "CONVCOMP.TXT" "DNLDTXWP.TXT," "DNLDZPWP.TXT," and "UPLOADWP.TXT."

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[1] The mention of any software products by name is not an official endorsement but used for illustrative purposes only.

[2] The PK commands for the files PKZIP.EXE and PKUNZIP.EXE work very similarly to DOS' copy command. You must be at the DOS prompt in order to use them. To view details on how to use either command, simply type the command PKZIP or PKUNZIP at the DOS prompt and hit RETURN. The files will automatically go into help mode and give you a brief explanation of how they work. If a user needs more direction, there is full explanation included in the PKZ204G.EXE file. Type PKZ204G.EXE file at the DOS prompt to expand the file and read the instruction files. Refer specifically to the help file called HINTS.TXT.

ATTACHMENT B

SURVEY

MAILING LIST FOR FUTURE PUBLICATIONS

Name: ______________________ Organization: ______________________

Position: ______________________ Address: ______________________

Phone: ______________________ ______________________

Fax: ______________________ ______________________

SURVEY:

DID YOU FIND THIS MANUAL USEFUL?

Please help us by answering the following questions:

A. PROFILE OF YOUR ORGANIZATION

( ) Trade Association ( ) Business ( ) Government Office

( ) Other ______________________

What product or service does your business/organization provide? ______________________

____

How old is your business/organization? ___ years

How many employees work in your business/organization? ___

B. TRAINING NEEDS

U.S. EPA and SEMARNAP plan to add sections to this manual or develop new manuals for other industries in the border area. Which industries should be addressed next? ______________________

( ) Textiles/Apparel ( ) Other ______________

What type of training would you attend?

( ) Technical Workshops ( ) General Training ( ) None ( ) Other ______________

U.S. EPA and SEMARNAP are considering holding training sessions on "pollution prevention."

What information would be useful to you in this area?

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C. USEFULNESS OF MANUAL

Did you find the format of this manual useful? ( ) Yes ( ) No

Did you find its content useful? ( ) Yes ( ) No

How would you improve it? ______________________________

____

What other information should be included? ______________________________

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Who else should receive this manual?

Name: ______________________ ______________________

Address: ______________________ ______________________

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D. ADDITIONAL COMMENTS

Please provide any additional comments on this manual and its usefulness.

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Please fold on the dotted line and mail. If you have any questions regarding this publication or would like additional information, you may contact ***U.S. EPA (214) 665-2258***, or ***SEMARNAP (52)5 553-9928***.

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Place
Stamp
Here
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ROBERT D. LAWRENCE (6EN-XP)
POLLUTION PREVENTION COORDINATOR
U.S. EPA REGION 6
1445 ROSS AVENUE
DALLAS TX 75202

(Place tape here)